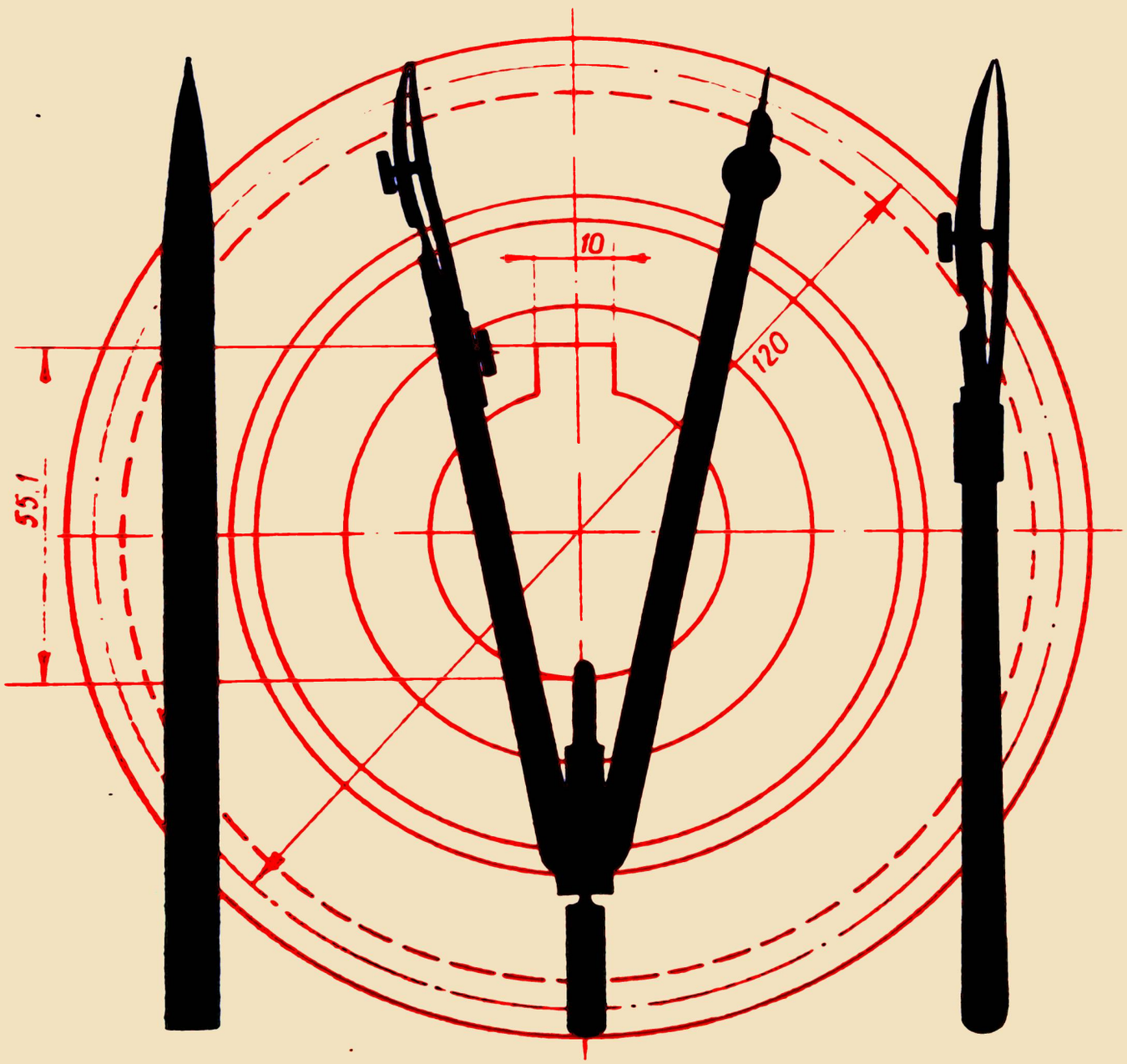
S. Bogolyubov, A. Voinov

ENGINEERING DRAWING



Mir Publishers

Other Mir Publishers' Books on Related Subjects

EXERCISES IN MACHINE DRAWING
by S. BOGOLYUBOV

A book of exercises in draughtsmanship for engineering apprentices and for mechanical engineering courses at secondary technical schools and colleges of technology. Uses examples taken from current industrial practice Gives explanations and examples for the solution of problems. Systematic performance of the exercises will help the student to master the requirements of the drawings used in mechanical engineering, and to acquire practical skills in draughtsmanship needed for further study and for working on his own.

ENGINEERING DRAWING

by I. VYSHNEPOLSKY

This book has been designed to enable the student who plans to enter the field of engineering or production to learn the language of engineering drawing and use it proficiently.

It is both a study book and a work book. Each section begins with a brief account of the study material followed by questions for self-testing. This is supplemented by a developed system of exercises composed of various types of problems.

The exercises usually require the student to analyze and compare pictorial views, or to select an answer from a suggested set. Some problems contain solution alternatives in a graphic form and the student is not required to copy what is given. Other problems suggest the student draw a missing view, read prepared drawings and so on.

To enable the student to check his or her answers the correct solutions are placed at the back of the book. This self-checking completes the cycle of study steps. This book is designed for technical schools which vary in emphasis on drawing. Where this emphasis is small the instructor may skip most of the graphic exercises. The various self-testing assignments will supply the student with the necessary knowledge in another way. Where the subject plays a more prominent role in the curriculum the graphic exercises can by introduced in due proportion, as dictated by the professional orientation and objectives of the course.

ENGINEERING DRAWING

С. К. БОГОЛЮБОВ И А. В. ВОИНОВ

КУРС ТЕХНИЧЕСКОГО ЧЕРЧЕНИЯ

ИЗДАТЕЛЬСТВО «МАШИНОСТРОЕНИЕ» · МОСКВА

S. BOGOLYUBOV and A. VOINOV

ENGINEERING DRAWING

A

Course

for

Technical Schools

of

Mechanical Engineering

*

Translated from the Russian

by

LEONID LEVANT

and

NICHOLAS WEINSTEIN

MIR PUBLISHERS · MOSCOW

First published 1968
Second printing 1973
Third printing 1976
Second edition (revised and supplemented) 1979
Second edition, second printing 1983
Third printing 1987

This book has been recommended for republication by Indian specialists under the programme of the Joint Indo-Soviet Board to make the best Soviet textbooks available for Indian students

© English Translation, Mir Publishers, 1986

Printed in the Union of Soviet Socialist Republics

CONTENTS

Introduction 9

I DRAWING TECHNIQUE

Chapter 1. **Instruments and Materials of Drawing** 13

Chapter 2. **Drawing Standards** 18
1. Sizes of Drawings 18
2. Title Blocks 19
3. Types of Lines 19
4. Use of Drawing Instruments 22
5. Lettering 25

II GEOMETRICAL CONSTRUCTIONS

Chapter 1. **Principal Geometrical Constructions** ... 32
1. Dividing Straight Lines into Equal Parts and Constructing Perpendiculars 32
2. Constructing Angles and Dividing Them Into Equal Parts 33
3. Finding the Centre of an Arc 36
4. Constructing Slopes and Tapers 36

Chapter 2. **Scales and Dimensioning** 39
1. Scales 39
2. Dimensioning 40

Chapter 3. **Dividing a Circle into Equal Parts** 44
1. Dividing a Circle into Four or Eight Equal Parts 44
2. Dividing a Circle into Three, Six and Twelve Equal Parts 44
3. Dividing a Circle into Five and Seven Equal Parts 46
4. Dividing a Circle into any Number of Equal Parts 49

Chapter 4. **Tangency Constructions** 51
1. Drawing Lines Tangent to a Circle ... 51
2. Conjunctions of Lines 52
3. Compound Curves 59

Chapter 5. **Non-circular Curves** 61
1. Construction of Conic Sections 61
2. The Sinusoid 64
3. The Spiral of Archimedes 65
4. The Involute 65
5. Cycloids 66

III FUNDAMENTALS OF DESCRIPTIVE GEOMETRY AND PROJECTION DRAWING

Chapter 1. **General** 70
1. Methods of Graphic Representation 71

Chapter 2. **Projections of a Point** 72
1. Projecting a Point on Two Planes of Projection 72
2. Projecting a Point on Three Planes of Projection 73
3. Coordinates of a Point 74
4. Relative Positions of Projections of Points in a Drawing 75

Chapter 3. **Projecting a Straight Line** 76
1. Projecting a Straight Line onto Two and Three Planes of Projection. Projecting Plane 76
2. Relative Positions of Projections of a Straight Line in Drawings 76
3. Angles Formed by a Straight Line and Projection Planes 79
4. Traces of a Straight Line 79
5. Relative Positions of Two Straight Lines 81

Chapter 4. **Projecting Plane Figures** 82
1. Ways of Specifying a Plane. Traces of a Plane 82
2. Projecting Planes and Oblique Planes 83
3. Projections of Points and Lines Lying on a Plane 84
4. Projections of Plane Figures 88
5. Relative Positions of Two Planes ... 90
6. A Line Cutting a Plane 91
7. Intersecting Planes 93

Chapter 5. **Methods of Revolution, Coincidence and Replacement of Planes of Projection** 95
1. Determining the True Image of Plane Figures 95
2. The Method of Revolution 96
3. The Coincidence Method 100
4. The Method of Replacing Projection Planes 102
5. Other Systems of Conventional Designation of Geometrical Elements 108

Chapter 6. **Axonometric Projections** 111
1. Types and Methods of Axonometric Projection 111
2. Orthographic Isometric Projections ... 112
3. Constructing Plane Figures in Isometry 114
4. Orthographic Dimetric Projections ... 122
5. Frontal Dimetric Projections 125

Chapter 7. **Technical Sketching** 128
1. Sketching Straight Lines, Plane Figures and Geometrical Solids 128
2. Sketching Machine Parts 132

Chapter 8. **Projections of Geometrical Solids** 133
1. Projecting a Cylinder 133
2. Projecting a Cone 133
3. Projecting a Pyramid 134
4. Projecting a Prism 134
5. Projecting a Sphere 135
6. Projecting a Ring and a Torus 136
7. Geometrical Solids as Elements of Machine Parts 136

8. Projections of a Point Located on the Surface of a Geometrical Solid 137
9. Projections of Lines Situated on Surfaces of Geometrical Solids 140

Chapter 9. **Cutting Geometrical Solids with Planes. Developed Surfaces of Geometrical Solids** 147
1. General Concepts 147
2. Intersection of a Plane and a Prism. Determining the True Size of the Section and Constructing a Developed Surface of a Prism 149
3. Intersection of a Plane and Cylinder. Development of a Cylinder 152
4. Intersection of a Plane and Pyramid. Development of a Pyramid 154
5. Intersection of a Plane and Right Circular Cone. Development of a Right Circular Cone 156
6. Development of a Sphere 158
7. Lines of Intersection 159

Chapter 10. **Intersections of Surfaces of Geometrical Solids** 162
1. Basic Facts 162
2. Intersections of a Straight Line with Surfaces of Geometrical Solids 163
3. General Concepts 165
4. Intersection of Cylindrical Surfaces 165
5. Intersection of Prisms 168
6. Intersection of a Cylinder and a Cone 169
7. Intersection of a Prism and a Sphere 171
8. Intersection of a Sphere and a Cylinder 172
9. Intersection of a Torus and a Cylinder 173
10. Constructing Intersection Lines by Spheres 173

Chapter 11. **Sectional Views and Sections** 177

IV MACHINE DRAWING

Chapter 1. **The Drawing as a Component of Standard Engineering Drawing Practice** ... 181
1. Features of Machine Drawing 181
2. Kinds of Products 182
3. Types of Drawings and Auxiliary Documents 183
4. The Title Block on Machine Drawings 185

Chapter 2. **Views, Sectional Views and Sections in Machine Drawings** 186
1. Views 188
2. Simple Sectional Views 190
3. Broken-Out Sections 192
4. Complex Sectional Views 193
5. Revolved Sections 194
6. Removed Sections 195
7. Conventional Symbols Used in Sectioning 197
8. Conventional Practice in Machine Drawing 198

Chapter 3. **Helical Surfaces and Threads** 203
1. Constructing Helices and Helical Surfaces 204
2. Threads and Thread Representation in Drawings 209
3. Vanish Threads, Necks and Chamfers 212
4. Thread Designations. Specifying Threads on Drawings 213
5. Bolted Joints 215
6. Studded Joints 218
7. Screw Fastenings 220
8. Simplified and Conventional Representations of Screw Joints 222
9. Standard Threaded Fastenings and Their Designation 223
10. Pipe Connections 224

Chapter 4. **Sketches and Working Drawings of Machine Elements** 227
1. Technical Sketching 227
2. Datum Surfaces 227
3. Dimensioning 228
4. Some Methods of Measuring Machine Parts. Measuring Tools 229
5. Designation of Surface Characteristics 235
6. Terminology of Common Machine Element Shapes 241
7. Materials and Their Designation 242
8. Steps in Making Sketches 244
9. Making Detail (Working) Drawings 246
10. Methods of Duplicating Drawings ... 253

Chapter 5. **Separable and Permanent Joints** 254
1. Cotter Joints 254
2. Keyed Joints 254
3. Splined Joints 257
4. Dowel Pin Joints 259
5. Riveted Joints 260
6. Welding Processes and Methods 262
7. Example of a Working Drawing of a Welded Joint 272

Chapter 6. **Gears and Gearing** 272
1. General 272
2. Gear Manufacture 273
3. Parameters of Toothed Gears 274
4. Types of Gears 279
5. Drawing Spur Gears 280
6. Training Detail Drawing of a Spur Gear 282
7. Making a Sketch from a Spur Gear 282
8. Drawing Single-Stage Spur and Helical Gearing 286
9. Straight Bevel Gearing 288
10. Drawing Straight Bevel Gears 288
11. Training Detail Drawing of a Straight Bevel Gear 291
12. Making a Sketch from a Straight Bevel Gear 291
13. Drawing Miter Gearing 294
14. Cylindrical Worm Gearing 295
15. Principal Parameters of Worms and Wormgears 295
16. Drawing a Worm and Wormgear Comprising a Worm Gearing Drive 297
17. Training Detail Drawing of a Wormgear 297
18. Training Detail Drawing of a Cylindrical Worm 298

19. Making Sketches from a Worm and a Wormgear 299
20. Drawing Worm Gearing 300
21. Types of Gearing and Their Elements 301
22. Ratchet Gearing 303
23. Chain Drives 305

Chapter 7. **Making, Reading and Detailing Training Assembly Drawings** 307
1. Set of Design Documents 307
2. Training Assembly Drawings 309
3. Locking Devices in Assembly Drawings 310
4. Packing Devices in Assembly Drawings 311
5. Drawing Lubricating Devices 313
6. Drawing Ball and Roller Bearings ... 314
7. Drawing Springs 314
8. Features of Assembly Processes and Their Representation 315
9. Tabular Drawings 315
10. Detailing Parts of an Assembly Unit 316
11. Simplification and Conventions for Assembly Drawings 317
12. Dimensioning Assembly Drawings ... 318
13. Limits of Size (Fits and Tolerances) 319
14. Geometrical Tolerances 322
15. Making a Training Assembly Drawing of a Finished Article 323
16. Assembly Drawings of Permanent Joints 331
17. Reading Training Assembly Drawings 334
18. Detailing an Assembly Drawing 334
19. Handling of Instruments, Stencils and Templets in Making Drawings 341

Chapter 8. **Reading and Drawing Diagrams** 342
1. Reading Diagrams 344
2. Making Gearing Diagrams 349

PREFACE

The continuous development of industry and the flood of new machine tools, machinery and equipment utilizing pneumatic, hydraulic and electronic devices for the complete mechanization and automation of production processes impose ever greater demands on the training of engineering draftsmen and technicians.

The course in technical drawing for technical schools and colleges therefore requires examples from the design and construction of such equipment, and this textbook aims to provide the student with extensive graphic material of just this kind, drawn from the latest industrial technology.

The authors' many years of teaching engineering drawing have convinced them that explanations based on the use of machine parts and components encourage the linking-up of theory and practice, develop the student's range of understanding and spatial visualization, acquaint them with technical terminology, and train them in the solution of drawing problems.

Illustrations have been selected from the latest technical literature and industrial practice; and to facilitate understanding of machine parts and components, drawings have been supplemented by photographs and axonometric representations.

Explanatory texts are brief, the aim being to teach the student to comprehend drawings and not simply to read accompanying explanations.

INTRODUCTION

A drawing is a graphic representation of an object, or a part of it, and is the result of creative thought by an engineer or technician. Modern engineering produces enormous numbers of articles, each first designed and presented in the form of a technical drawing, and each manufactured on the basis of this drawing. Designing an item involves making sketches and technical drawings, and the appropriate calculations. Sometimes a number of alternative designs are represented in drawings, and the best then selected.

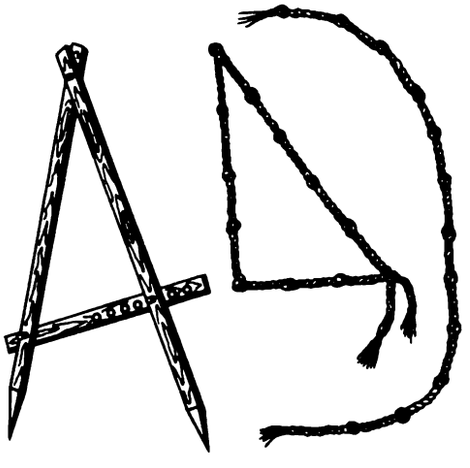
Technical drawing has a history of its own. Articles have been represented in the form of drawings since ancient times, and drawing in general was a means of communication between people long before systems of writing emerged.

The first real technical drawings, known as "plans", appeared when it became necessary not only to depict an existing object, but to create new things, when whole structures had to be built: fortresses, houses, and the like. Ordinarily, these drawings were executed full size right on the ground on the site of the future structure, which required specialized instruments like the large wooden measuring device shown in Fig. 1*a* and the right-angled triangle made of rope depicted in Fig. 1*b*.

Later, these plan drawings were made on papyrus, parchment, wood, or canvas on reduced scales, and attempted to reflect the shape and dimensions of the objects themselves. Early Egyptian papyri already depicted buildings and structures in two views: front (elevation) and top (plan).

Mediaeval craftsmen had many ingenious ways of casting metals and alloys, making weapons, and erecting buildings. The remains of old buildings show that they were thoroughly familiar with geometrical forms and quite capable of selecting the best solution for a technical problem.

Manuscripts of the 13th and 14th centuries, for example, have many pictorial drawings illustrating the methods of manufacturing various items, like the guns in Fig. 2. From the drawing, which comes from an old Russian chronicle, it can be seen that the barrel was made by furnace



(*a*) (*b*)

Fig. 1

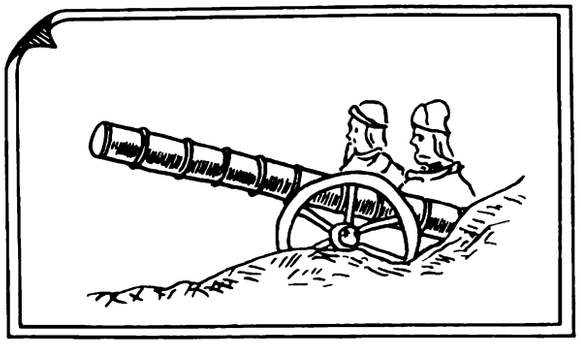


Fig. 2

or forge welding, and was reinforced by mounted hoops.

Very often a single representation would include a combined plan (top view) and elevation (front or side view) of some structure, like the bridge in Fig. 3. This was inconvenient, however, and so the two views came to be separated, thus initiating projection drawing, in which two, and even three, planes of projection were used.

During the 16th and early 17th centuries orders for articles from metal-working factories were usually based on models rather than drawings; but in the 17th century drawings began to predominate. At first they were not made to any kind of scale, but dimensions were always indicated.

As shipbuilding, for example, developed, more exact drawings were required, made to a strict scale. The drawings made by shipwrights and their helpers by the beginning of the 18th century were of a very advanced character and utilized three projections, in which all three dimensions of the ship — length, beam, and height were indicated (Fig. 4).

In 1798 the French engineer Gaspar Monge published his *Descriptive Geometry*, a book that laid the foundation for projection drawing as we know it today. Important as his contribution was, however (he generalized the method of rectangular projection of objects onto two mutually perpendicular planes), it is important to remember that long before the appearance of descriptive geometry, craftsmen were producing drawings that posed and solved problems theoretically treated by him. Certain Russian drawings of the 18th century, for example, were executed with extreme care and drawn in various coloured inks. They indicated cutaway portions of hollow articles, with the cutaway coloured according to the type of material.

The drawings of the Russian inventors I. Polzunov and I. Kulibin (Fig. 5*a* and *b*) clearly show that they well knew how to make exact projection drawings long before the end of the 18th century.

Descriptive geometry was further developed during the 19th century and right up to the present, Russian and Soviet specialists making their own valuable contribution to the theory of representation, the elaboration of standards, and the methodology of teaching mechanical drawing. Modern projection drawing is used in every field of technology, and underlies the manufacture of all mass-produced articles and components, and assembly work.

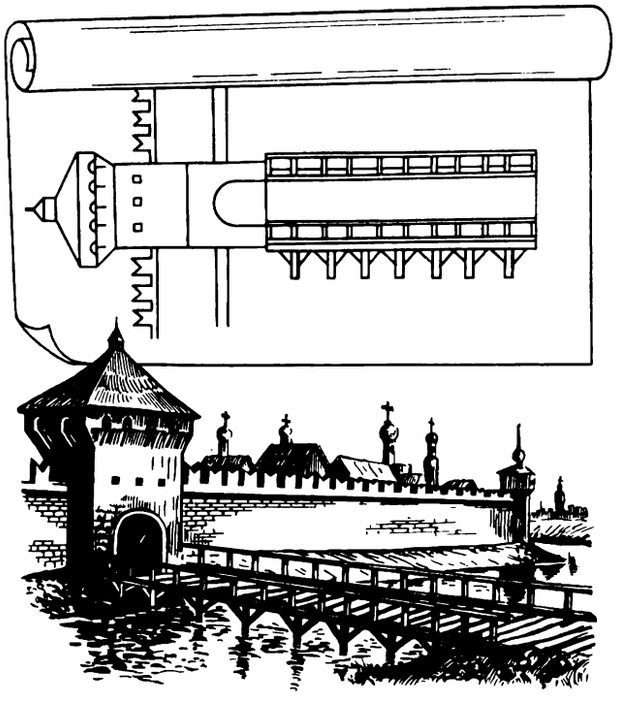


Fig. 3

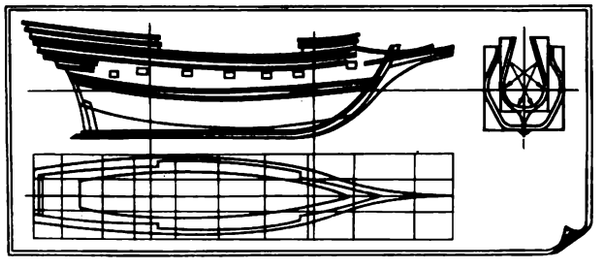


Fig. 4

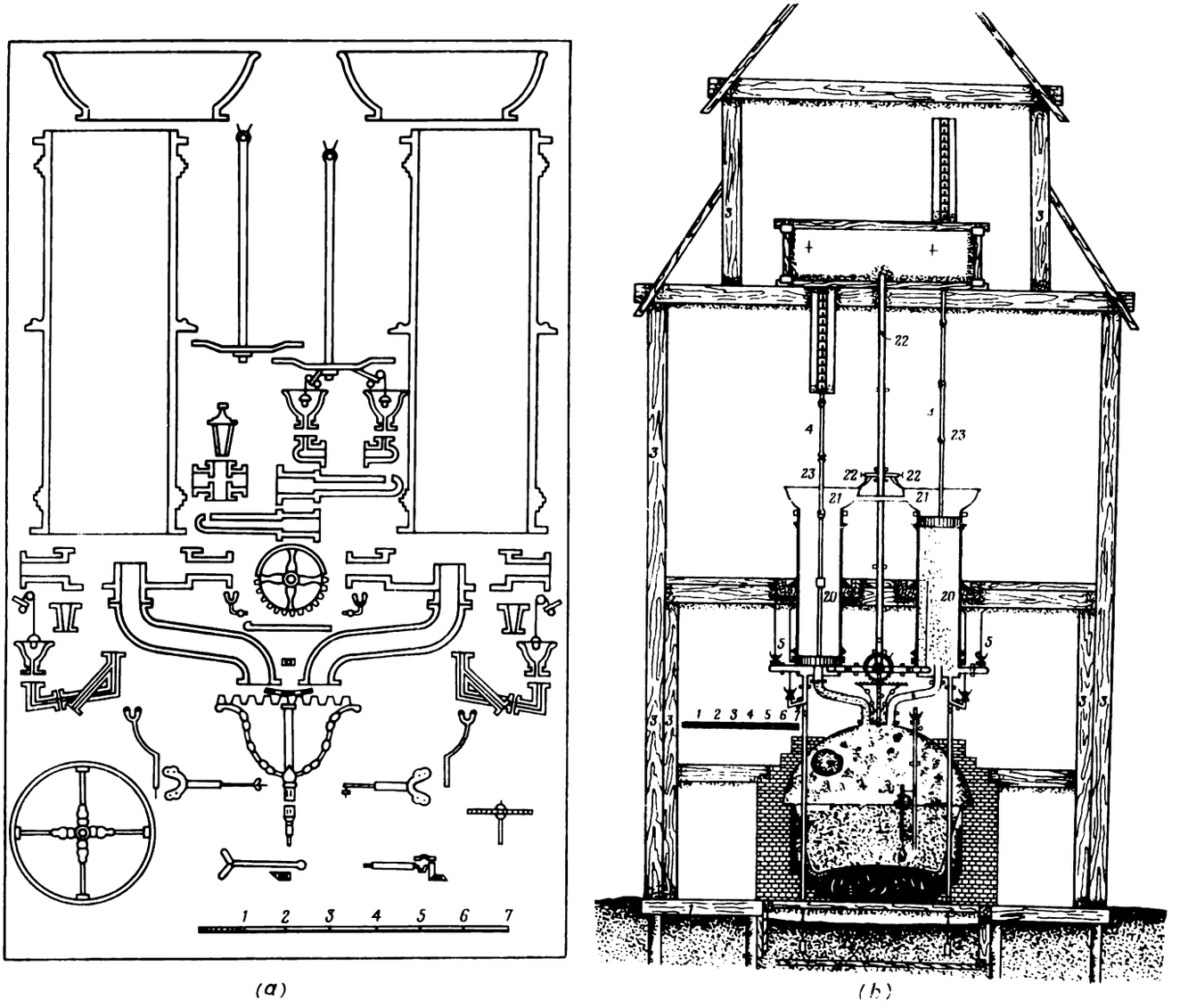


Fig. 5

I

DRAWING TECHNIQUE

CHAPTER 1

INSTRUMENTS AND MATERIALS OF DRAWING

All drawings are made by means of various instruments. The quality of a drawing depends to a large extent on the quality, adjustment and care of the instruments.

Each student must have a set of drawing instruments and materials (see Fig. 6).

1. **Drawing Board.** The paper, on which a drawing is to be made, is fixed with thumbtacks to a specially designed drawing board (Fig. 6*c*). Drawing boards are usually made of linden because thumbtacks readily penetrate its soft wood. The thumbtacks are unpinned with the aid of a remover specially designed for this purpose (Fig. 6*o*). The size of the drawing board should be such as to provide enough space for a standard sheet of drawing paper Size 24 measuring 594×841 mm (according to the USSR Standard).

2. **Triangles.** Two types of triangles are used for drawing purposes: 45°-45° and 60°-30° (Fig. 6*a* and *b*). Triangles must be tested for accuracy of their angles each time they are to be used. Proceed as follows: put the triangle with one of its legs against the straight edge of a tested ruler and draw a straight line along the other side with a well sharpened pencil (Fig. 7). Then turn the triangle through 180° and draw another line as before. The two pencil lines must coincide (Fig. 7*a*), if not, the angle between the adjacent sides is not equal to 90°, and such a triangle should not be used in drawing as it is inaccurate (Fig. 7*b*).

3. **T-square.** The common T-square consists of two parts, a long ruler (or blade) and a cross-piece (or head) at one end fitted at right angles to the blade (Fig. 6*e*). When using the T-square its head should be tightly pressed against the left-hand edge of the drawing board.

The T-square head, in turn, consists of two parts, one fixed and the other hinged. The latter can be fastened at any angle by means of a wing nut. The hinged part of the head is turned to draw parallel lines at any angles to the edges of the drawing board (Fig. 8*b*). To keep the T-square in good condition, careful handling is required. After use it should be hung on a nail to prevent it from warping.

With the aid of triangles and a T-square parallel and perpendicular lines are drawn (Fig. 8*a*). Vertical lines are drawn along the long leg of the triangle, its short leg sliding against the T-square blade. Lines at angles of 45, 60 and 30 degrees with the horizontal are drawn along the hypotenuse of the respective triangle.

It is very convenient to use a T-square fitted with rollers and a cord (Fig. 8*c*).

4. **French Curve.** French curves are used to draw irregular curves (Fig. 6*g*). It is desirable to have several French curves of different curvature. The edges of a French curve must be absolutely smooth. The French curve is one of the most difficult instruments to use skilfully. Its shape should comprise curves most widely used in drawings and gradually merging into each other.

5. **Protractor.** This instrument is employed for laying out and measuring angles (Fig. 6*d*).

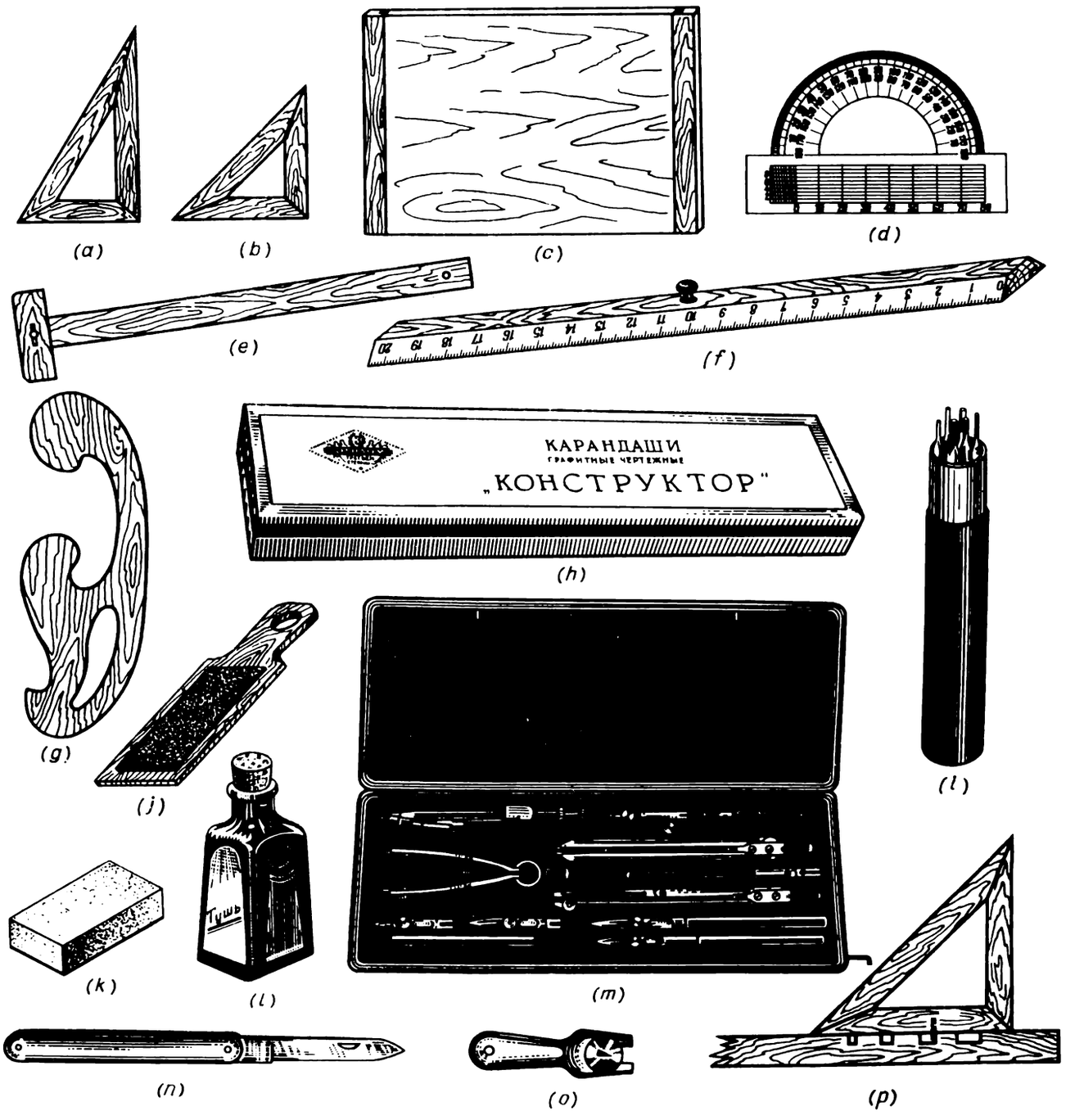

(a)
(b)
(c)
(d)
(e)
(f)
КАРАНДАШИ
ГРАФИТНЫЕ ЧЕРТЕЖНЫЕ
„КОНСТРУКТОР"
(h)
(g)
(j)
(l)
Тушь
(k)
(i)
(m)
(n)
(o)
(p)

Fig. 6

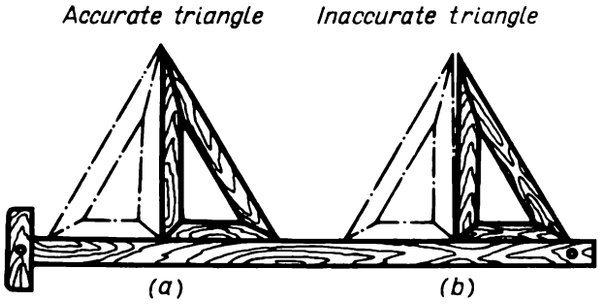


Fig. 7

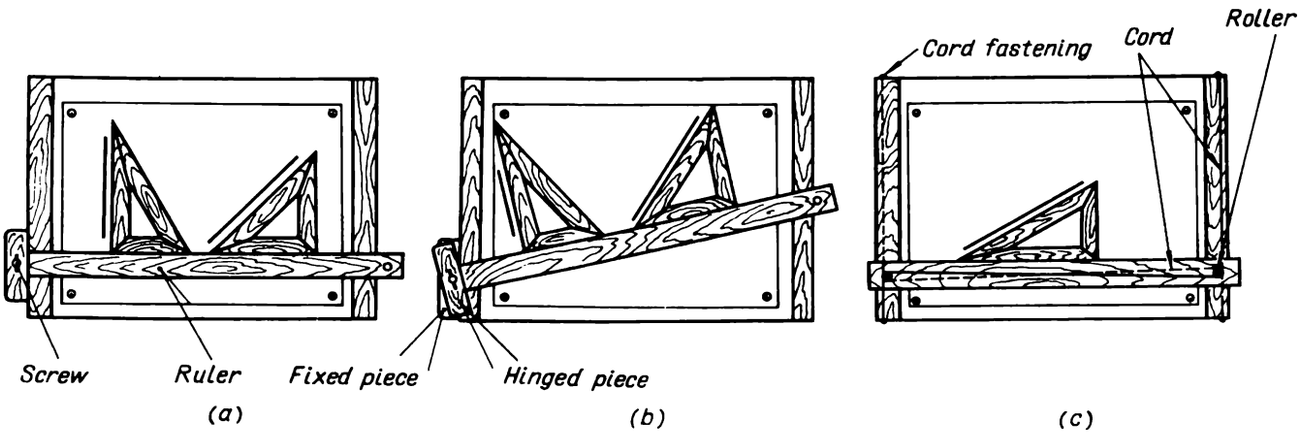


Fig. 8

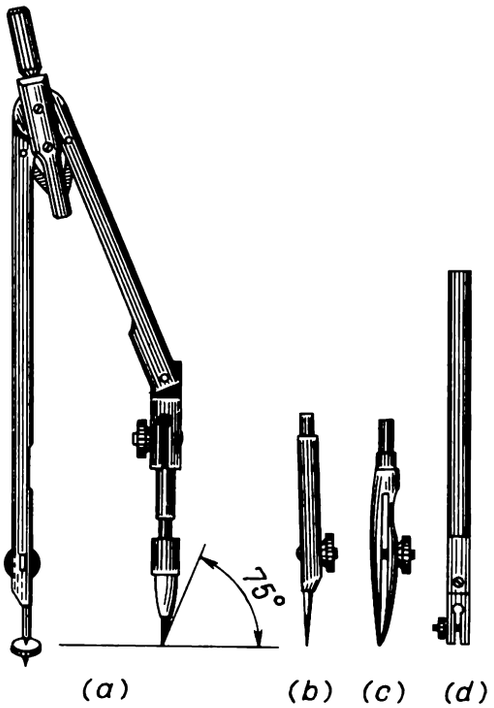


Fig. 9

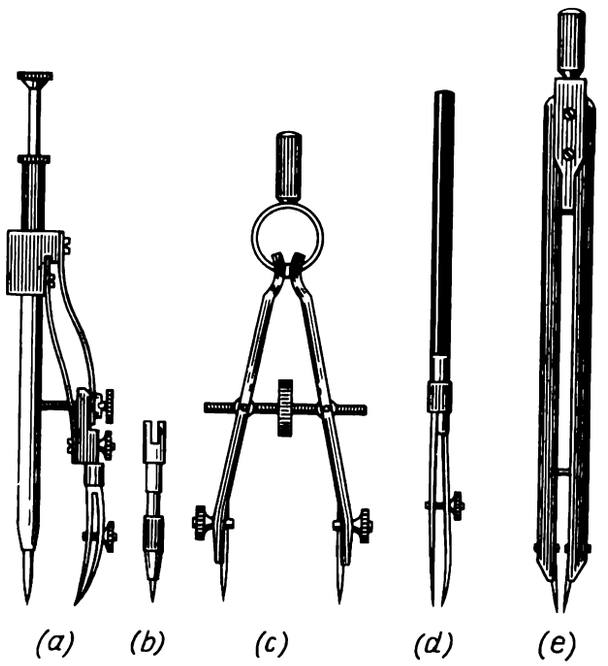


Fig. 10

6. **Scale.** Scales with bevelled edges graduated in millimetres are usually used (Fig. 6*f*).

7. **Section Liner.** This device is employed for the rapid and even spacing of cross-hatching lines at an angle of 45 degrees with the horizontal. Such instruments are usually made by students themselves. The one shown in Fig. 6*p* may serve as an illustration. A short metal pin (say, a headless nail) is inserted into one of the legs of a triangle and the blade is indented with rectangular cuts of different width. The depth of the cuts should somewhat exceed the projecting length of the pin. In this device the spacing of cross-hatching lines is determined by the width of the cuts.

In section lining the blade and the triangle are shifted in turn after each individual cross-hatching line is drawn. Be sure that at the moment of drawing, the metal pin is held tightly against the edge of the cut.

Without such a device it is very difficult to attain even spacing of cross-hatching lines, and, most important of all, the eyes will soon get tired. Moreover, even the slightest difference in spacing is clearly noticeable and ruins the drawing.

8. **Case of Instruments** — a set of compasses, ruling pens and other drawing instruments arranged in a specially designed case (Fig. 6*m*).

(a) *Compass* (Fig. 9*a*). The compass is used to draw circles and arcs both in pencil and in ink. It consists of two legs pivoted at the top. One leg is equipped with a steel needle attached with a screw, the other, shorter, leg is provided with a socket for detachable inserts (furnished with a lead for drawing circles in pencil), Fig. 9*a*, with a ruling pen for ink (Fig. 9*c*), and, finally, with another steel needle (Fig. 9*b*) to be used as dividers, i.e., for transferring measurements

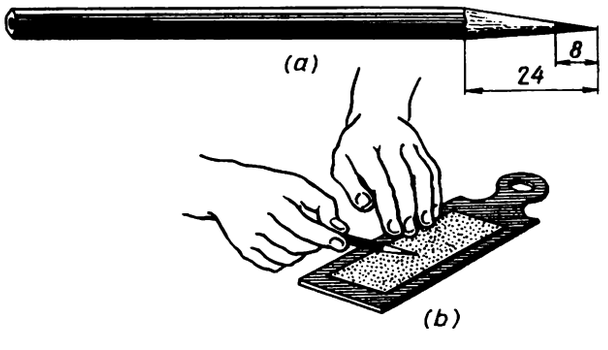


Fig. 11

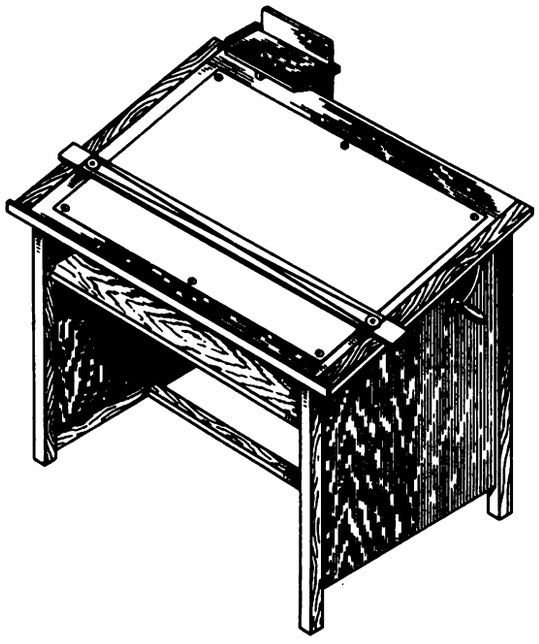


Fig. 12

and for dividing lines into any number of equal parts. In drawing circles of larger radii a lengthening bar (Fig. 9*d*) should be used. When a large number of concentric circles are to be drawn the needle of the compass should be put in a metal centre which has the shape of a thumbtack.

(b) *Drop pen.* The drop pen, as shown in Fig. 10*a* and *b*, is used for drawing very small circles. The pencil or pen point spins around the central axis and can be raised and lowered.

(c) *Ruling pen.* This instrument is designed for inking drawings. The distance between the nibs of the pen can be adjusted by means of a screw (Fig. 10*d*) to obtain lines of various thickness.

(d) *Dividers.* The dividers (shown in Fig. 10*c* and *e*) are used chiefly for transferring distances and occasionally for dividing spaces into equal parts.

9. **Pencil.** Uniform quality and appropriate hardness determine the selection of pencils.

The importance of a correctly prepared pencil point cannot be overstressed. Fig. 11*a* shows a properly sharpened pencil, Fig. 11*b* pointing the lead with fine sandpaper pasted up on a small wooden board.

10. **Drafting Desk.** It is good practice to place the drawing board on a drafting desk. Such a

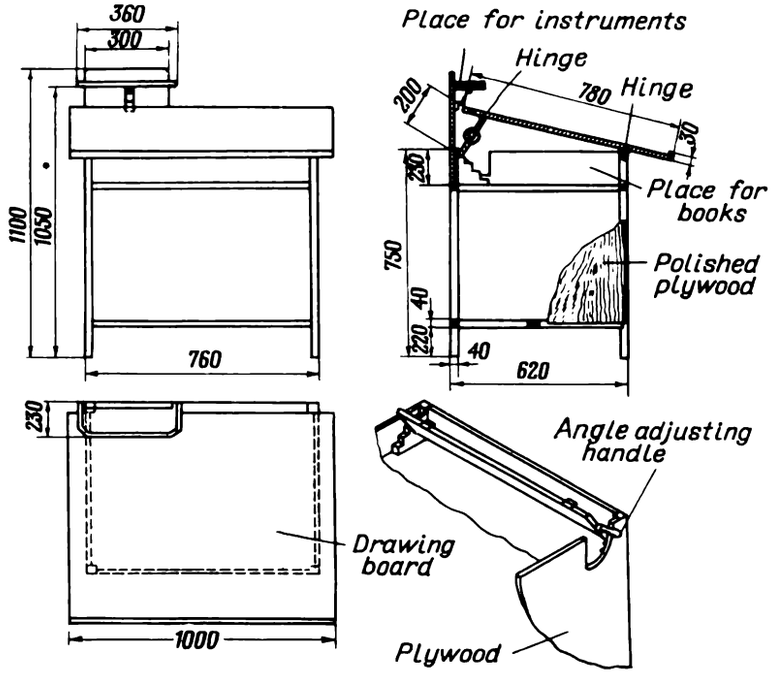

360
300
1100
1050
760
230
1000
Drawing board
Place for instruments
Hinge
780
Hinge
200
30
250
Place for books
750
Polished plywood
40
220
40
620
Angle adjusting handle
Plywood

Fig. 13

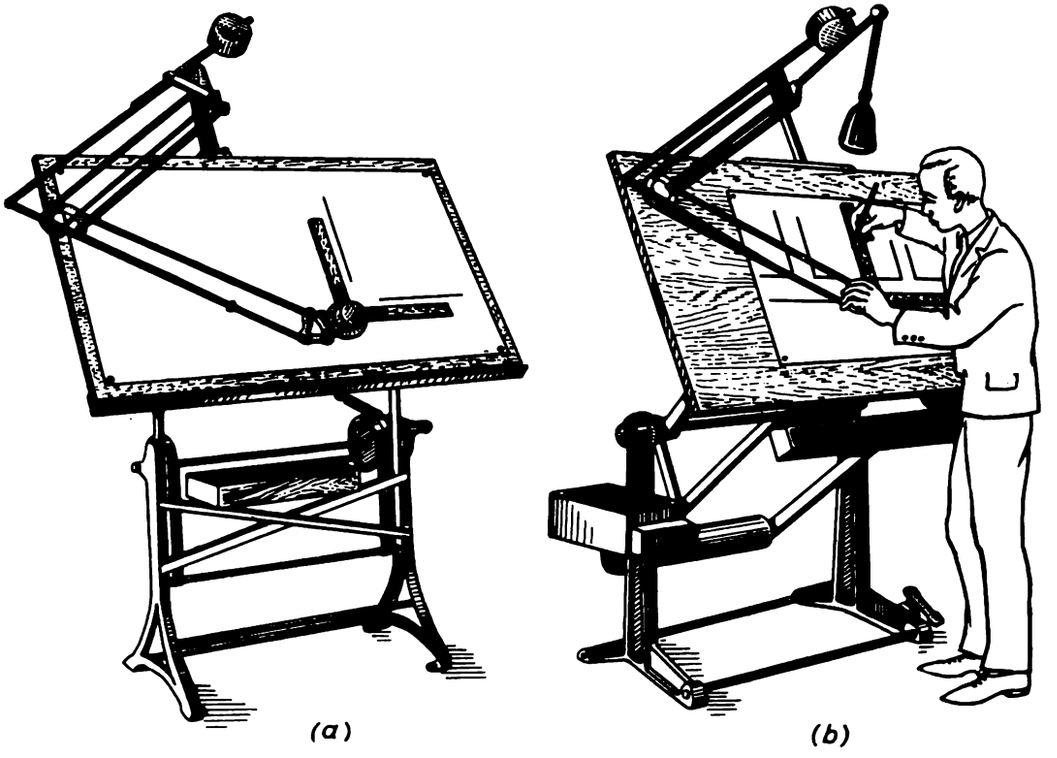

(a)
(b)

Fig. 14

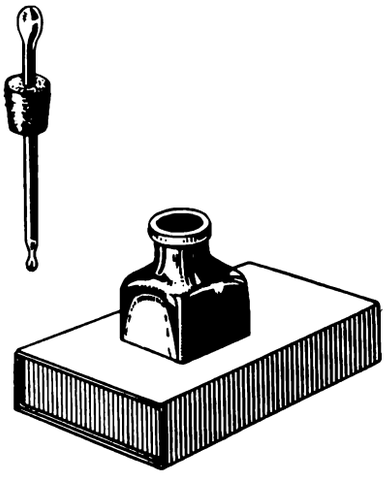


Fig. 15

desk should be steady and convenient; it should be fitted with a device for changing the angle of the drawing board with the horizontal and a shelf for pencils, instruments and machine parts. With such a desk it is recommended to use a parallel ruling straight edge (a blade equipped with pulleys and a cord, see Fig. 12). Fig. 13 presents a drawing to which a desk can be made by students.

Drafting desks vary in design. Shown in Fig. 14 are drafting machines combining the advantages of the T-square, triangles, and scales. In operation, this device keeps the two blades always parallel to their original position no matter where they are moved on the sheet. The two blades, which may be simple straight edges or straight edges with scales along them, are accurately set at right angles to each other. The blades are removable, and hence a variety of scales may be used. The adjusting head has a protractor with vernier attachment so that the blades may be set and clamped at any desired angle. Considerable saving of time results from the use of this machine.

The ink bottle should always be secured in a steady box (see Fig. 15) to avoid upsetting it with the consequent damage to drawings and equipment. Inserted in the bottle through the cork is a rod for filling the ruling pen.

The student should learn how to handle instruments. While drawing he should always keep them in good order.

After use they should be cleaned and kept in a dry place. This practice protects wooden instruments against warping and metal ones against corrosion.

CHAPTER 2

DRAWING STANDARDS

1. SIZES OF DRAWINGS

All engineering drawings are made on sheets of paper of strictly defined sizes, which are set forth in the USSR Standard.

The use of standard sizes saves paper and ensures convenient storage of drawings. The USSR Standard establishes five preferred sizes for drawings as tabulated below:

Table 1

Size designation	11	12	22	24	44
Sheet dimensions, mm	297×210	297×420	594×420	594×841	1189×841

Drawing size is designated by two figures: the first indicates how many times one side of the drawing is greater than 297 mm, the second how many times the other side is greater than 210 mm. The basic size for drawings is Size 11 measuring 297 mm by 210 mm. All other sizes comprise several Sizes 11. Thus, Size 12 is made up of two Sizes 11 with adjoining long sides (Fig. 16). The next Size 22 comprises four Sizes 11, as is seen also from Fig. 16.

Table 2

Size designation	Sheet dimensions, mm	Size designation	Sheet dimensions, mm
13	297×631	32	892×420
14	297×841	42	1189×420
15	297×1051	52	1486×420
16	297×1261	62	1783×420
17	297×1472	72	2081×420
25	594×1051	54	1486×841
26	594×1261	64	1783×841
27	594×1472	74	2081×841
28	594×1682	84	2378×841
29	594×1892	94	2675×841

The product of the figures in the size designation indicates the number of Sizes 11 (measuring 297×210 mm) contained in the given size. For example, Size 24 comprises 2×4, that is eight Sizes 11.

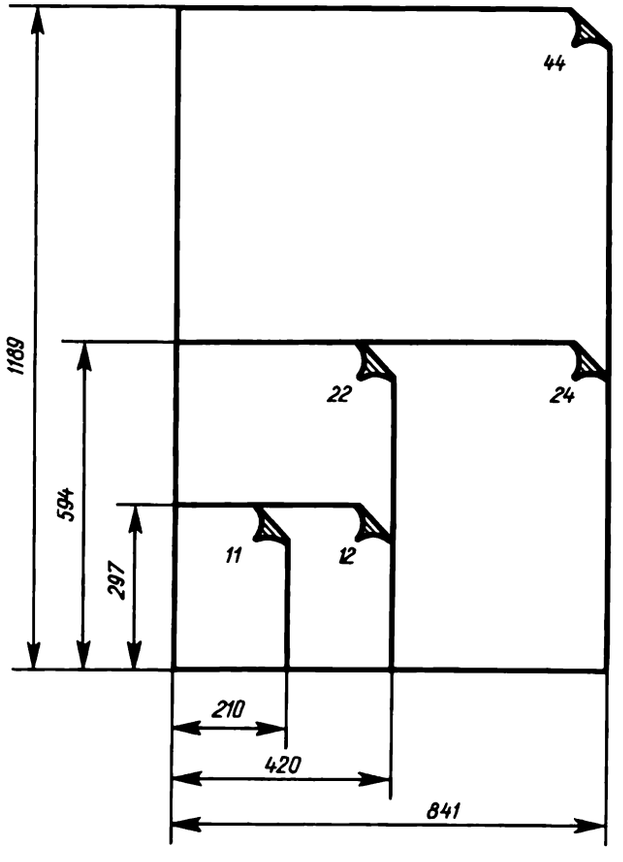


Fig. 16

In addition to the above preferred sizes, the standard provides for other sizes (see Table 2), which are also comprised of a whole number of Sizes 11 (Fig. 17, Size 25).

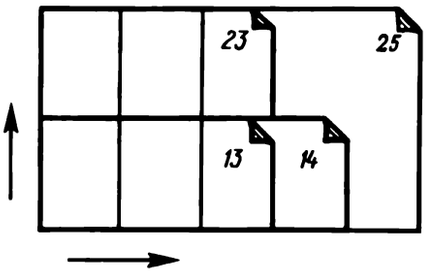


Fig. 17

2. TITLE BLOCKS

All production and training drawings have a title block in a rectangle located in the lower right-hand corner of the sheet. It contains such information as the name of the plant or educational institution, the description or title of the drawing, dates, signatures and other pertinent data.

The size and content of the title block are stipulated by standards of engineering drawing practice and are dealt with in detail in Part IV — *Machine Drawing*. A considerably simplified title block is proposed for drawing courses in geometric and projection drawing. Examples of such title blocks are illustrated in Figs. 18 and 20.

In addition to the name of the educational institution, title of the drawing, dates and signatures, such a simplified title block should indicate which year of school the student is in, the number of his class, his speciality (for instance, the index for foundry practice could be *FP*).

The title block should be arranged along the short side of the sheet for Size 11 sheets and along either the short or long side for sheets of other sizes (Fig. 19).

3. TYPES OF LINES

In engineering drawing various types of lines are used. Line thickness depends on the size, complexity and purpose of the drawing.

There are four principal types of lines: continuous (thick, thin and wavy); short-dash; dot-and-dash or chain (thick and thin) and open (see Fig. 21).

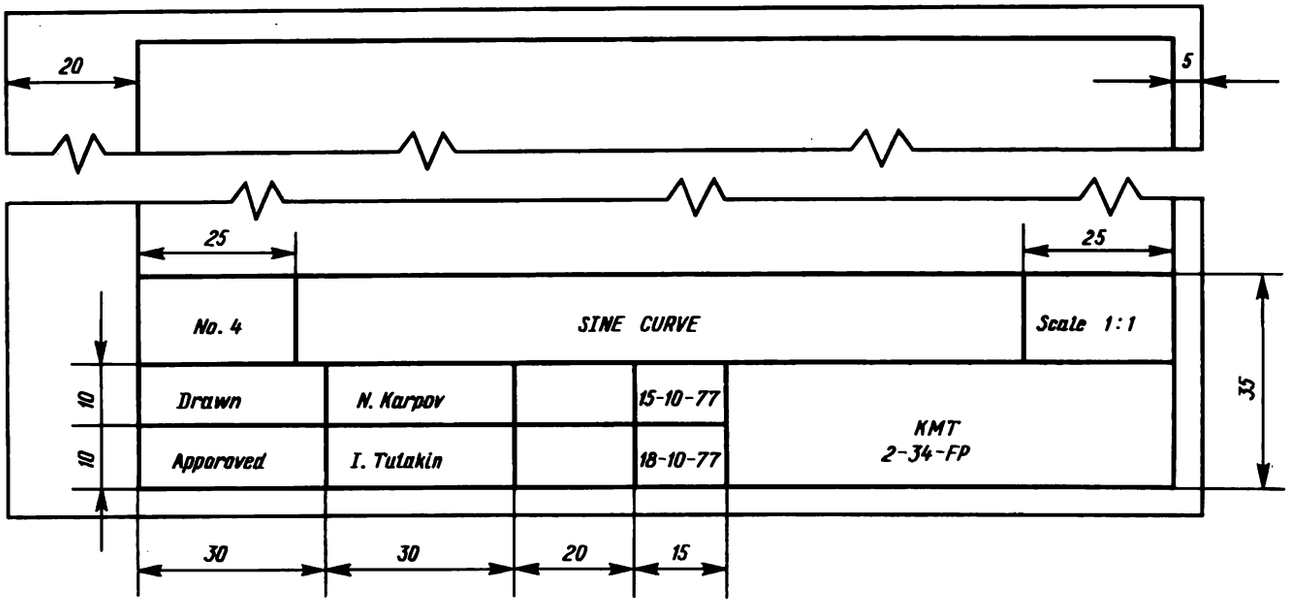


Fig. 18

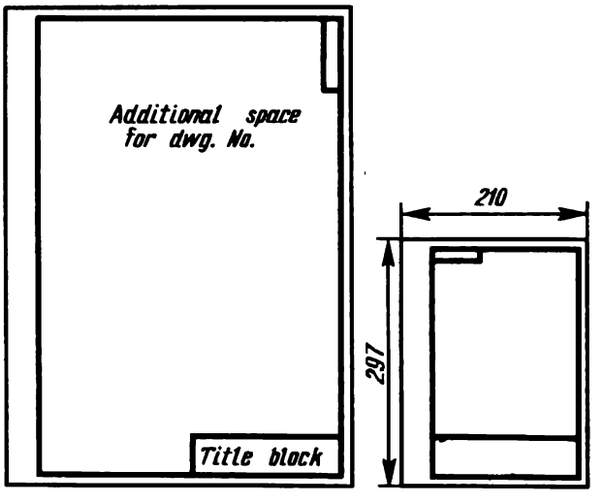


Fig. 19

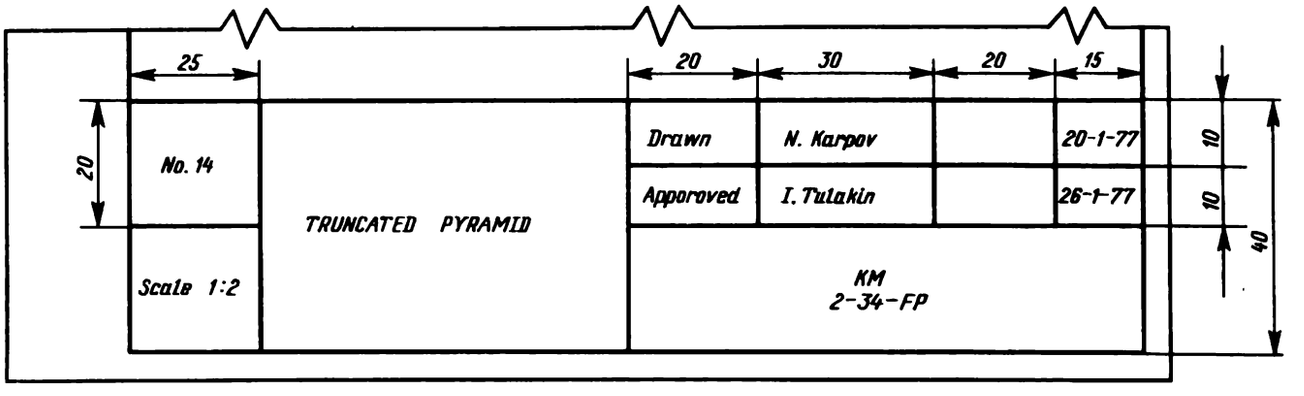


Fig. 20

Lines used in drawings

Type	Sample	Thickness
Thick continuous		s=0.6 to 1.5 mm
Thin continuous		s/2 to s/3
Wavy continuous		s/2 to s/3
Short-dash		s/2 to s/3
Long chain (thin)		s/2 to s/3
Short chain (thick)		s/2 to 2s/3
Open (thick)		s to 1.5s

Fig. 21

Typical applications of some of the above listed types of lines are shown in Fig. 22 (drawing of a valve plug).

Thick continuous lines used for drawing visible outlines should be 0.6 to 1.5 mm thick. Their thickness (designated as *s*) depends on the dimensions of the part and the complexity, size and purpose of the drawing. The chosen line thickness should be equal for all views in a given drawing presented in one and the same scale. *Thin continuous lines* used for extension and dimensions lines should be from one half to one third the thickness of lines specified as thick.

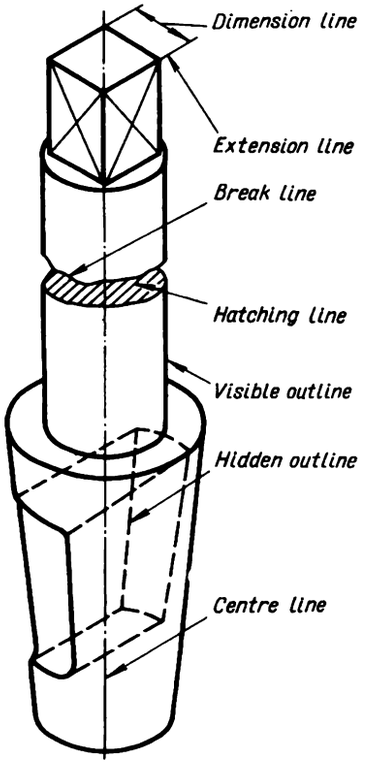


Fig. 22

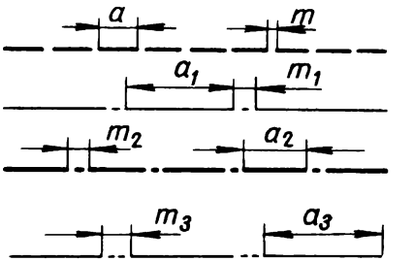


Fig. 23

Continuous lines of the same thickness (*s*/3 and less) are also used for *hatching* in sections, the hatching lines being spaced at 2 to 8 mm depending on the area to be cross-hatched. Breaks are shown by a *wavy line* *s*/2 mm and less thick.

Short-dash lines are used for hidden outlines and hidden intersections. The length of a dash *(a)* is from 2 to 8 mm, its thickness from *s*/2 to *s*/3, the spacing between dashes *(m)* being approximately 1/2 to 1/4 of their length (Fig. 23).

Thin dot-and-dash lines with long dashes (or *long chain* lines) are used for axes and centre lines which are usually *s*/3 mm and less thick with dashes approximately 5 to 30 mm long (a_1) spaced at 3 to 5 mm (m_1), see Fig. 23.

In thick dot-and-dash lines with short dashes (or *short chain* lines) the length of a dash (a_2)

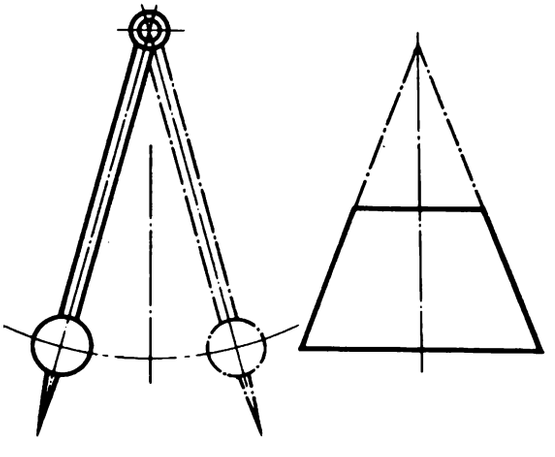


Fig. 24

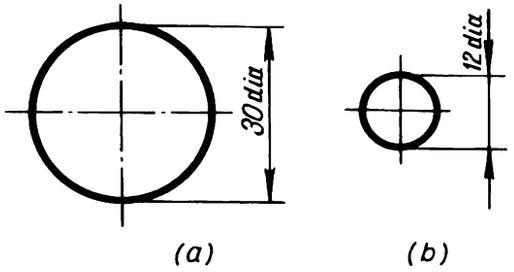


Fig. 25

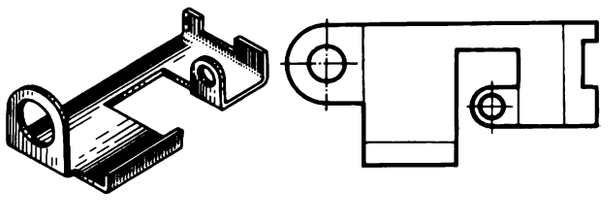


Fig. 26

is 3 to 8 mm, the spacing (m_2) being 3 to 4 mm. For small drawings a_2 may be still less.

Typical applications of thick short chain lines are shown in Fig. 24: the right-hand extreme position of a pendulum and the cut-off portion of a truncated cone.

Centres of circles should be marked by two intersecting dashes as in Fig. 25*a*. For circles of diameters less than 12 mm the centre lines are usually drawn with thin continuous lines as in Fig. 25*b*.

Thin continuous lines are used to show a surface smoothly merging into another as well as to indicate bending lines (see Fig. 26).

4. USE OF DRAWING INSTRUMENTS

The student should learn first of all how to prepare a sheet of drawing paper and properly fasten it to the board. It is usually secured to the drawing board by means of thumbtacks. Make sure that they do not interfere with the T-square and triangles. First fasten the top left-hand corner of the sheet. Then stretch the paper with your palm in the direction of the arrow in Fig. 27 and fasten the bottom right-hand corner. The remaining two corners should be fastened in the same manner.

The position of the T-square on the drawing board and its handling are shown in Fig. 28. Pressing the crosspiece against the board with your left hand let it slide along the left-hand edge, holding the blade lightly with your right hand.

Move the triangle along the blade with your right hand holding the T-square with your left hand. In drawing a line hold the pencil in a slightly inclined position as shown in Fig. 28.

The compass is usually held with the thumb and index finger of the right hand; circles are drawn clockwise (Fig. 29*a*). Small circles are drawn with a drop pen (Fig. 29*b*). For extra large circles a compass fitted with a lengthening bar should be used (Fig. 29*c*). Distances are transferred by means of dividers (Fig. 30).

When inking a drawing the ruling pen should be held in the same manner as the drawing pencil, that is, slightly inclined in the direction of motion and perpendicular to the paper if viewed from the side. Great care should be exercised to keep the pen in the correct position, since even a minute deviation may lead to disastrous results. Fig. 31 shows the correct relative positions of the ruling pen and the ruler or triangle. Both nibs of the pen must touch the paper and, when held perpendicular to the paper, the point of the fixed nib is kept at the proper distance from the ruler due to the curvature of the nib. A white space should always

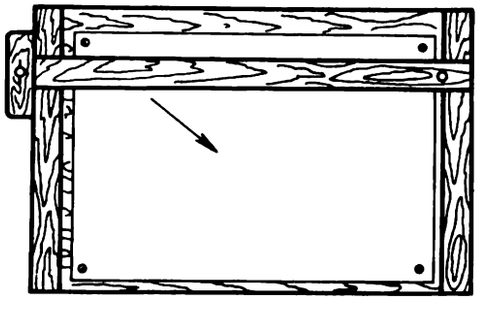


Fig. 27

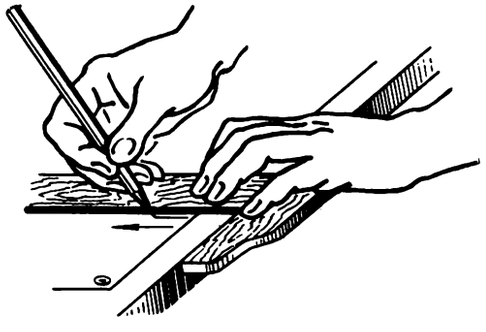


Fig. 28

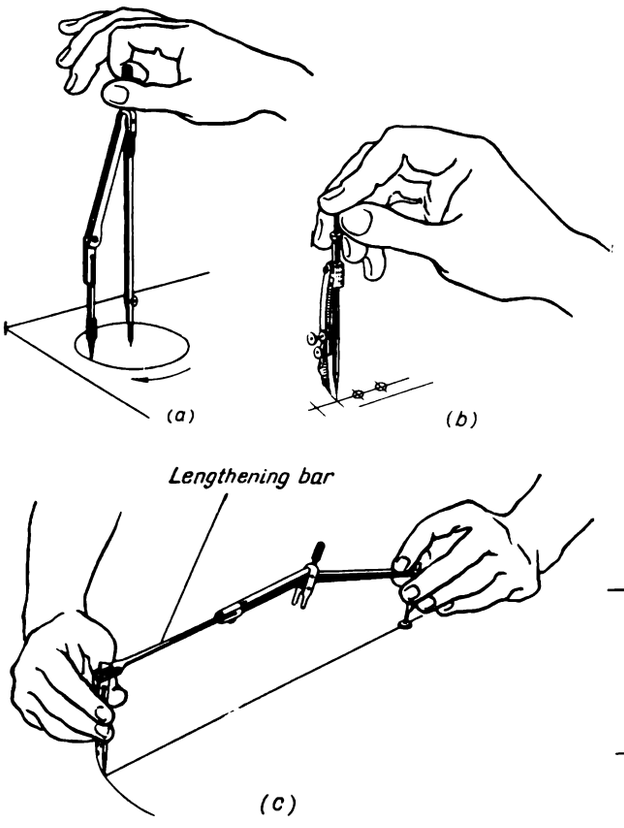


Fig. 29

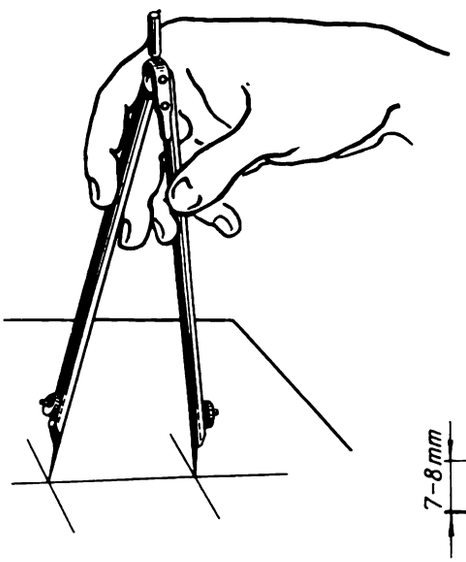


Fig. 30

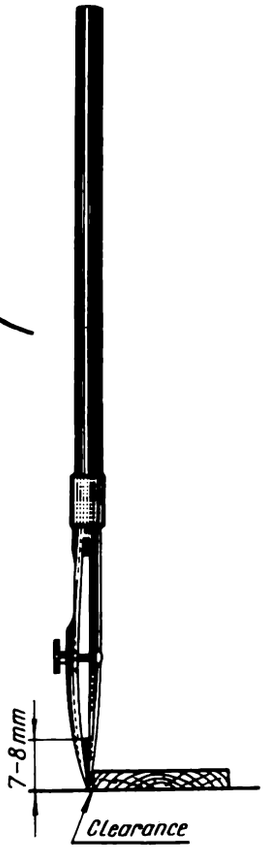


Fig. 31

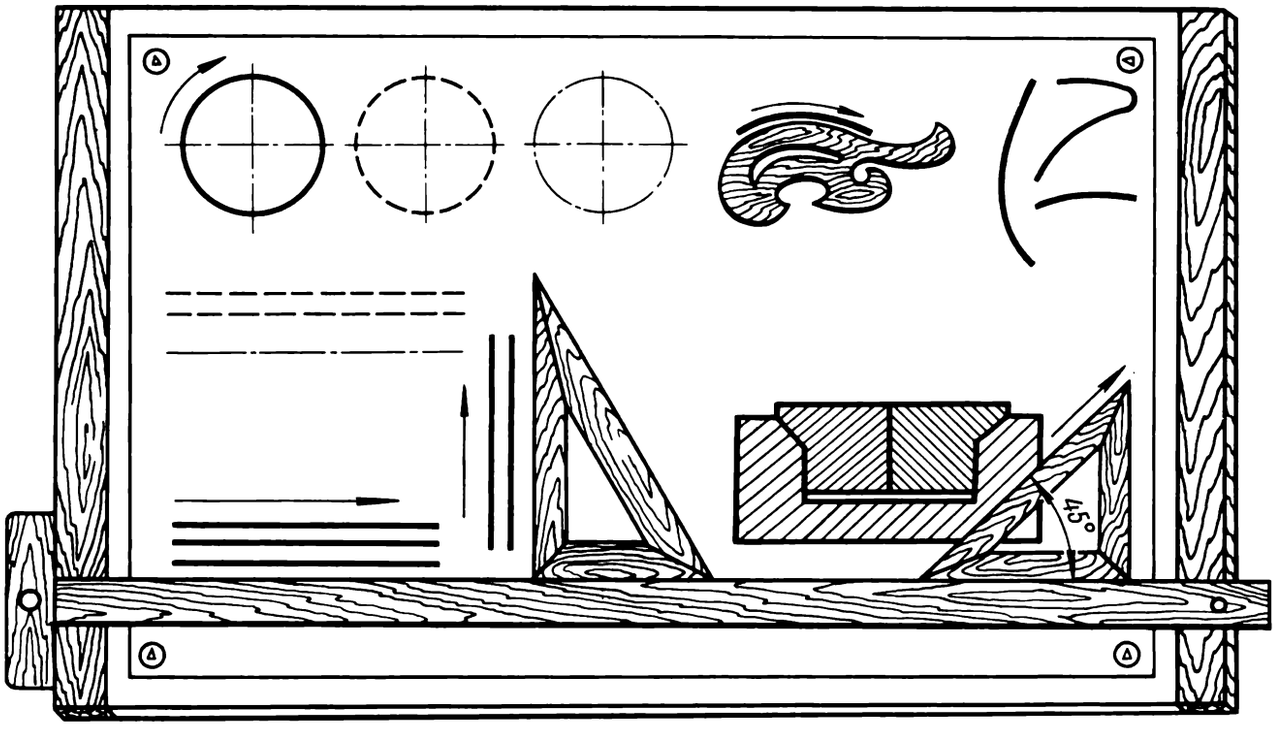


Fig. 32

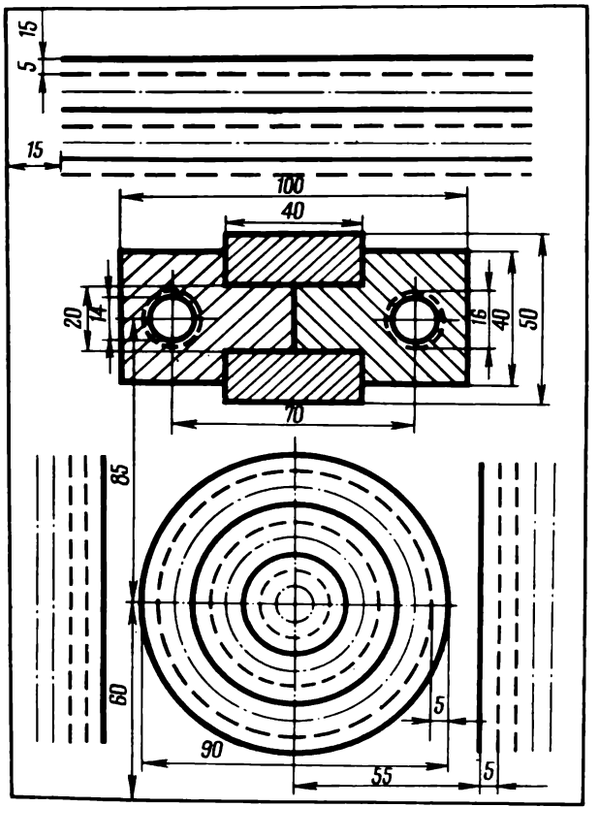


Fig. 33

show between the line and the ruler. The ink should not stand more than 7 to 8 mm high in the pen, as the weight of a higher column will cause the ink to run out and make a blot.

For the student to become skilled in drawing lines and using the drawing instruments it is necessary to do a number of exercises. These consist in drawing horizontal lines with the aid of a T-square, vertical lines with a T-square and triangle, circles by using a compass and, finally, non-circular curves by means of a French curve. It is necessary to remember in what direction the various lines are to be drawn. As shown in Fig. 32 horizontal lines are usually drawn from left to right, vertical from bottom to top, circles and curves clockwise.

Cross-hatching, or section lining, is done by drawing light, inclined and uniformly spaced lines. Section lines should be drawn at an angle of 45° to the axis or a visible line chosen as a base. They may slope either to the left or to the right. If two adjacent parts of a machine are to be cross-hatched, they should be distinguished from one another by a different direction of the section lining. In case of three adjacent parts one part should differ from the other two by the spacing of the section lines.

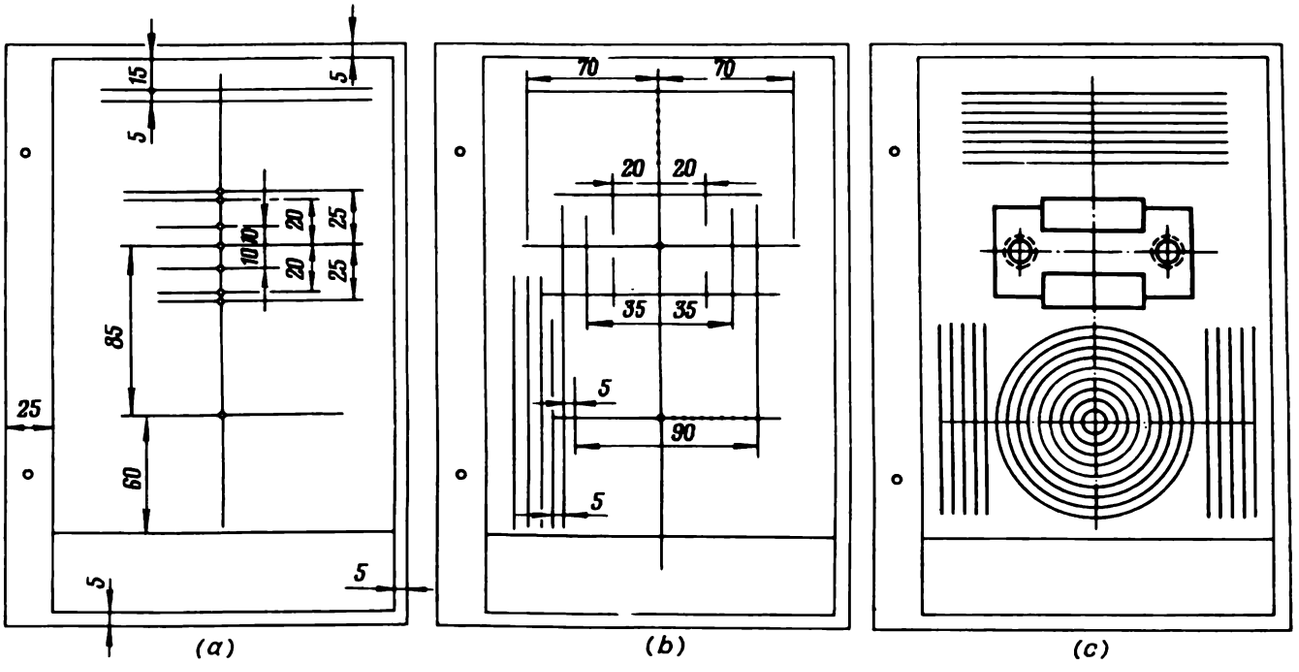


Fig. 34

Shown in Fig. 33 is a typical exercise in drawing various lines, Fig. 34*a*, *b* and *c* indicating the successive stages in doing it. This exercise should be done on a sheet Size 11.

Prior to making a drawing it is necessary first to draw trimming lines determining the size of the drawing. This may be done in the following way: with the aid of a ruler or T-square draw diagonals on the paper sheet; then, through their intersection, draw a horizontal line by the use of a T-square and triangle, then a vertical line perpendicular to it. Next, on these lines mark off lengths equal to one half of the required size (297×210) on both sides from the centre point. Through the points thus obtained, draw the horizontal and vertical trimming lines of the drawing.

If drawings of several parts are to be made on one sheet of paper, then, after drawing trimming lines determining the size of the whole drawing, the sheet is divided into separate smaller sizes for each individual part by appropriate trimming lines. Then draw margin lines which limit the working area of each drawing on the four sides (see Fig. 34). The margin lines should be strictly parallel to the trimming lines and spaced 5 mm from them at the right, top and bottom while at the left a margin of 25 mm should be left (Fig. 34*a*) for binding. In the bottom right-hand corner of the sheet space should be left for the title block. The dimensions of the title block are specified in the appropriate standard. After these preparatory operations the student may proceed with the drawing.

Mark off the given dimensions on the vertical line drawn through the centre point. Through the points thus obtained draw horizontal lines; on both sides of the vertical axis mark off the required dimensions (Fig. 34*b*). Join the obtained points with thin lines (Fig. 34*c*), which are then finished with a soft pencil or inked. In this exercise dimensioning is not necessary.

5. LETTERING

The drawing should be carefully made and carefully lettered. The character of the line work and the lettering gives the drawing what is known as technique, a phase of drafting which is too often neglected. Inscriptions accompanying the drawing should be made in clear and pleasing letters and figures. Since all mechanical parts are made to drawings, careless lettering may result in rejects.

The styles of letters and figures to be used for engineering drawings are also standardized. For the forms and slant of the capital and lower-case letters of the Russian, Latin and Greek alphabets and figures see Figs. 36, 37 and 38.

The following sizes of characters are recommended: 2.5, 3.5, 5, 7, 10, and 14. The size is determined by the height *h* (in mm) of capital letters (Tables 3*a* and 3*b*). The letters and figures have a slant of 75° to the horizontal. In certain cases drawings may be lettered in vertical characters (Fig. 35).

Fig 35

The above tables indicate recommended heights and widths of letters and figures, and their line thickness; slight variations are permissible. The tables contain established standards for Russian (Table 3*a*) and Latin (Table 3*b*) letters and figures. All the characters are specified both in millimetres and by the conventional ratio based on the height of capital letters.

To learn the construction of the letters and figures as well as the method of their making, use guide lines forming a kind of grid. Since all the sizes of the characters are proportional to the quantity 1/7 *h*, the grid is composed of eight horizontal lines intersected by a series of parallel lines slanted at an angle of 75° to the horizontal. The slanted lines are drawn with the aid of a T-square and two triangles — one 45°-45°, the other 30°-60° (see Fig. 41*b*). Shown in Figs. 36, 37, 38, and 39 are examples of slant lettering constructed with the aid of guide lines. The prescribed width of the letters, line thickness, spaces between letters and other elements are shown in these examples. Fig. 40*a* and *b* illustrates slant lettering made with the aid of a simplified grid.

The three thin guide lines drawn in the middle serve the following purposes: the line which divides the height of letters into two equal parts is meant for constructing the horizontal elements of the letters and figures; in making the letters *Б*, *В*, *Е*, and *Н* the horizontal elements

Table 3a

The Russian Alphabet

Specification	Designation	Ratio between the height and other dimensions	Size					
			2.5	3.5	5	7	10	14
			mm					
Height of capital letters and figures	h	—	2.5	3.5	5	7	10	14
Height of lower-case letters (except *б, в, д, р, у, ф*)	h_1	$h_1 \approx 5/7h$	—	2.5	3.5	5	7	10
Height of lower-case letters *б, в, д, р, у, ф*	h	—	—	3.5	5	7	10	14
Width of capital letters (except *Д, Ж, М, Ф, Ш, Щ, Ъ, Ы, Ю*) and figures (except 1)	b	$b \approx 5/7h$	1.8	2.5	3.5	5	7	10
Width of capital letters *Д, Ж, Ф, Ш, Щ, Ы, Ю*	b_1	$b_1 = h$	2.5	3.5	5	7	10	14
Width of capital letters *М* and *Ъ*	b_2	$b_2 \approx 6/7h$	2.2	3	4.5	6	9	12
Width of lower-case letters (except *ж, м, т, ф, ш, щ, ъ, ы, ю*)	b_3	$b_3 \approx 3/7h$	—	1.5	2.2	3	4.3	6
Width of lower-case letters *ж, м, т, ф, ш, щ, ъ, ы, ю*	b_4	$b_4 \approx 4/7h$	—	2.0	3.0	4	6	8
Width of figure *1*	b_5	$b_5 \approx 2/7h$	0.7	1.0	1.5	2	3	4
Line thickness of capital letters and figures	b_6	$b_6 \approx 1/7h$	0.35	0.5	0.7	1.0	1.5	2.0
Line thickness of lower-case letters	b_7	$b_7 \approx 1/10h$	0.25	0.35	0.5	0.7	1.0	1.5
Spaces between letters in words and between figures in numbers	A	$A \approx 2/7h$	0.7	1.0	1.5	2.0	3.0	4.0
Spaces between words and between numbers, not less than	A_1	$A_1 \approx h$	2.5	3.5	5	7	10	14
Spaces between lines of lettering, not less than	A_2	$A_2 \approx 3/2h$	4	5.5	7.5	11	15	21

Table 3b

The Latin Alphabet

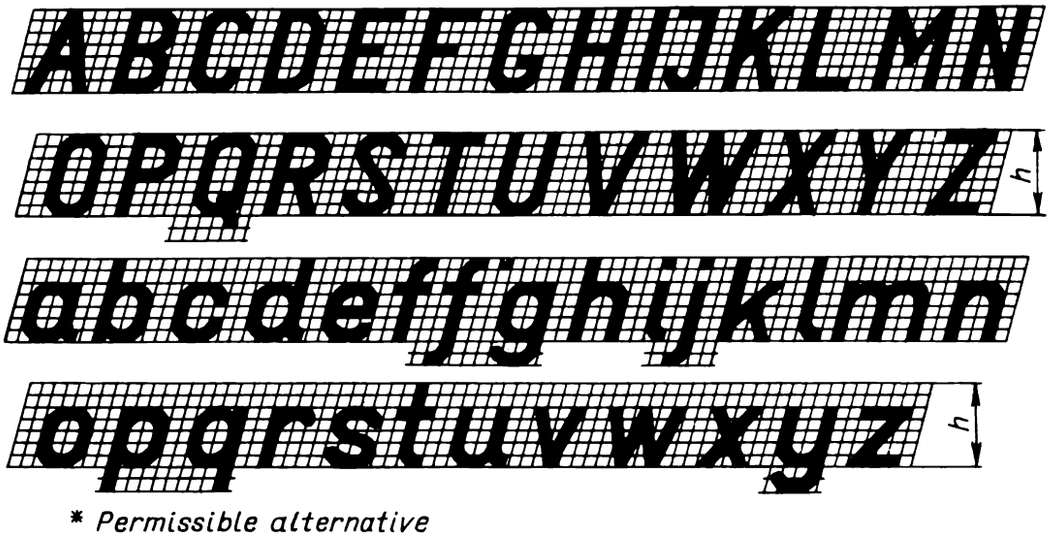
Specification	Designation	Specification	Designation
Height of capital letters and figures	h	Width of lower-case letters i, j, l, and figure 1	$b_6 = 2/7h$
Height of lower-case letters (except *b, d, f, g, h, i, j, k, l, p, q, t,* and *y*)	$h_1 = 5/7h$	Widht of lower-case letters f, r, and t	$b_7 = 3/7h$
Height of lower-case letters *b, d, f, g, h, i, j, k, l, p, q, t,* and *y*	h	Width of lower-case letters m and w	$b_8 = h$
Width of capital letters (except *A, I, J, M,* and *W*) and figures (except 1)	$b = 4/7h$	Line thickness of capital letters and figures	$b_9 = 1/7h$
Width of capital letter *I*	$b_1 = 1/7h$	Line thickness of lower-case letters	$b_{10} = 1/10h$
Width of capital letter *J*	$b_2 = 3/7h$	Spaces between letters in words and between figures in numbers	$A = 2/7h$
Width of capital letters *A* and *M*	$b_3 = 5/7h$	Spaces between words and between numbers, not less than	$A_1 = h$
Width of capital letter *W*	$b_4 = h$	Spaces between lines of lettering, not less than	$A_2 = 1\ 1/2h$
Width of lower-case letters (except *f, i, j, l, m, r, t,* and *w*)	$b_5 = 4/7h$		

Russian Alphabet

Size 10

Fig. 36

Latin alphabet



* *Permissible alternative*

Fig. 37

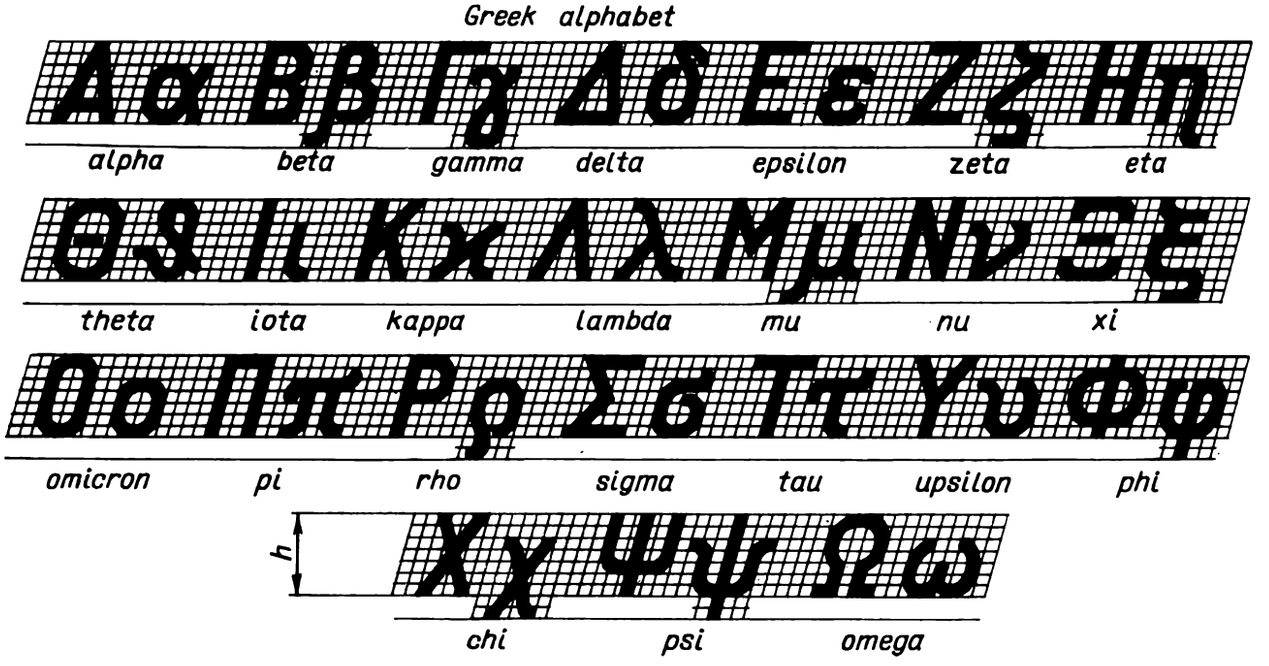

Greek alphabet
alpha beta gamma delta epsilon zeta eta
theta iota kappa lambda mu nu xi
omicron pi rho sigma tau upsilon phi
h
chi psi omega

Fig. 38

are to be drawn above the middle guide line, and below it in the letters *P*, *Ч*, *У*, and *Я*.

In the above examples the sizes of the letters and figures were taken from the appropriate standard (Table 3*a*) in conformity with the *conventional ratios* based on *h*. In Fig. 41*a* the Russian word "Болт" (Bolt) is lettered according to the *actual sizes* given in the same table.

In lettering machine drawings small sizes are used: Size 7 and less. To speed up the process the student must learn the correct forming of characters, as shown in Fig. 41*b*. As can be seen from the figure, the capitals of the standard lettering style may be divided conventionally into three groups.

The first group comprises letters and figures of simple shape, as for example, *И*, *П* and *Г*, that can be constructed without drawing auxiliary guide lines.

The characters belonging to the second group, such as *H*, *Ч*, *Я* require an additional horizontal guide line cutting their height in half. The middle elements of these letters are above (as in *H*) or below the guide line.

The characters in the third group (*C*, *O* and some others) depend for their construction on two horizontal guide lines which divide their height into three equal parts. The upper and lower parts of these characters are rounded. The basic form in this group is that of the letter *O*. The middle elements of this letter should be straight. In the letter *3* and figures *3* and *8* the upper part should be somewhat narrower than the lower.

In certain cases drawings may be lettered with a vertical style of lettering. When there is a shortage of space, the letters and figures may be compressed, or narrowed. Both inclined and

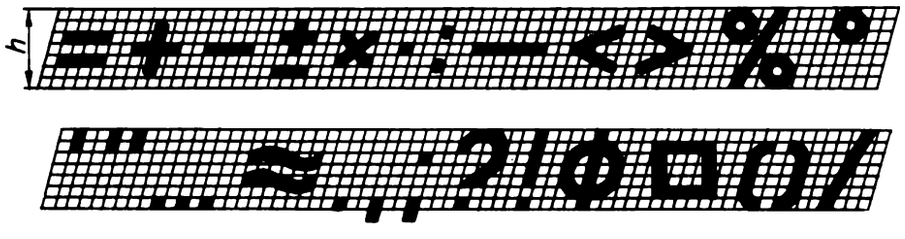


Fig. 39

Size 10

Fig. 40

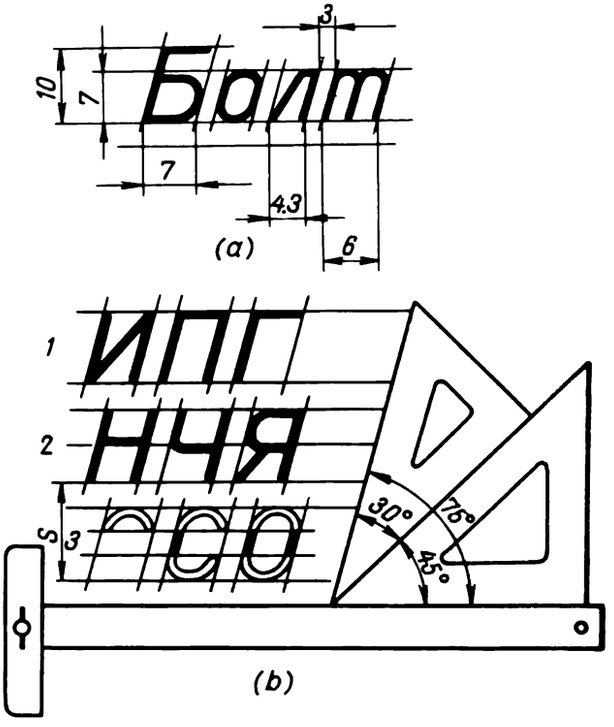


Fig. 41

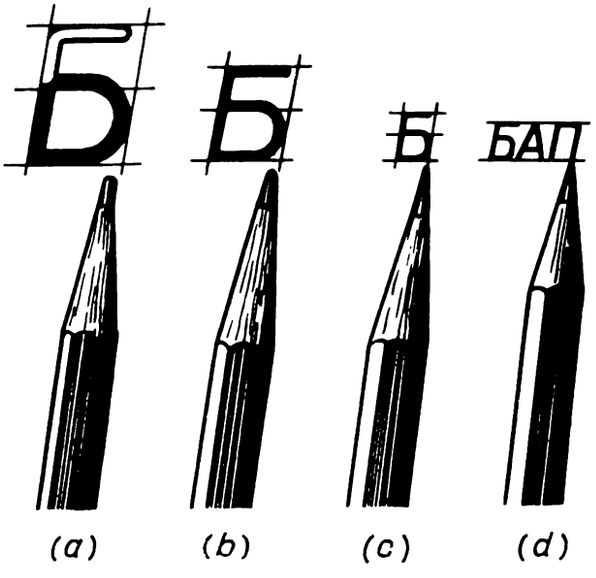


Fig. 42

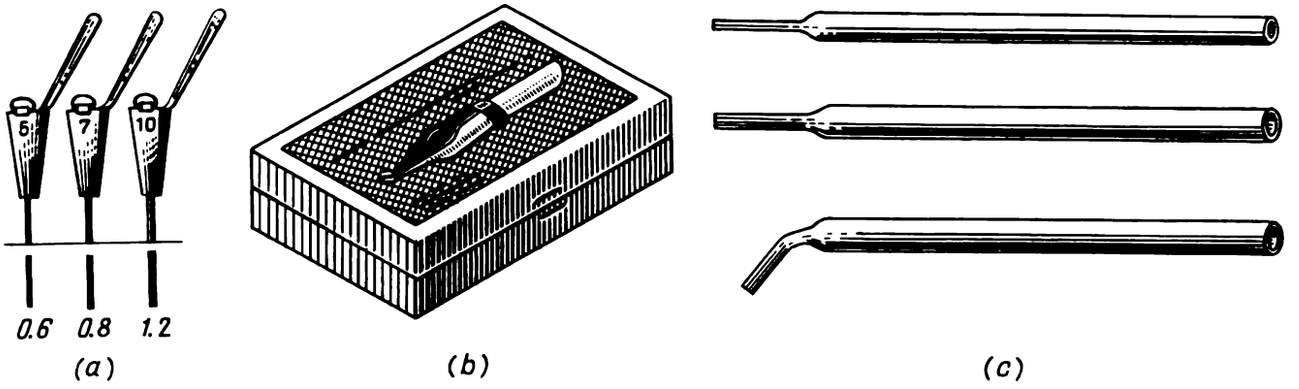


Fig. 43

vertical styles may be compressed. Here the width may be taken in fractions of the height *h* of capital letters of the next smaller size, the shape of the letters and figures being retained.

Inscriptions may be made on drawings either with capital letters only or with lower-case letters, the first letter being capitalized. In the latter case the line thickness of the capital and lower-case letters should be equal.

In certain combinations of letters (such as *V* and *A*, *L* and *T*, etc.) the space between them is reduced so as to make it seem equal to that between other letters.

In making drawings letters and figures are finished with a soft pencil or inked. Inscriptions lettered with characters of large and medium sizes are finished with a blunt lead (see Fig. 42*a* and *b*), small-size letters and figures with a well sharpened point (same figure, *c* and *d*).

The lettering is inked with the aid of specially designed pens (shown in Fig. 43*a*), drawing pens (Fig. 43*b*) or glass tubes (see Figs. 6*i* and 43*c*). The diameter of the inking end of a tube corresponds to the specified line thickness of the required size of lettering. For the sake of convenience the glass tube can be bent (as in Fig. 43*c*) on a flame.

After using a glass tube, place it into the ink bottle. Do not leave it on the drawing board, as it will become clogged with the dry ink.

Shown in Fig. 44 is a standard sheet of paper prepared for an exercise in lettering (for Size 10 letters). The sequence is as follows. Draw two vertical lines which will indicate the limits for

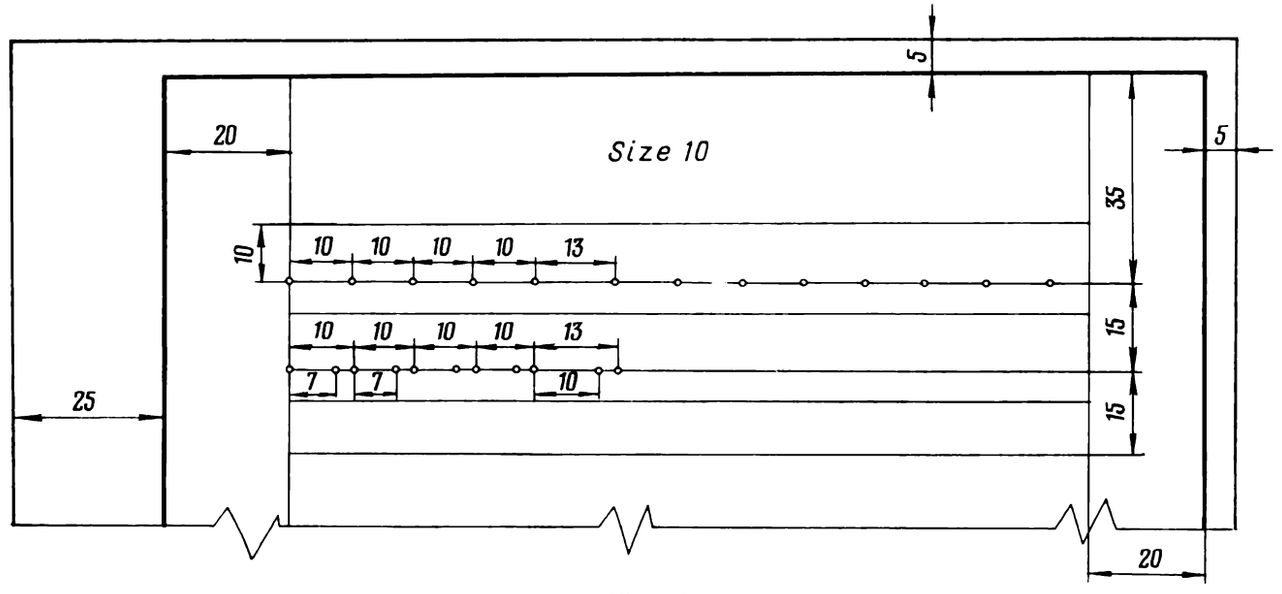


Fig. 44

the lines of lettering (approximately 20 mm from the margin lines). Then draw several parallel horizontal lines spaced at 15 mm, which will serve as lower guide lines, and the corresponding upper guide lines to limit the height of the lettering to 10 mm. Mark off sections of 10 mm on the lower guide lines throughout their length, 10 mm being the sum of the letter width (7 mm) and the space between letters (3 mm). For constructing "wide" letters sections of 13 mm must be marked off.

On mastering this operation the student should try free-hand lettering, without making use of guide lines, and observing the requirements of the standard.

Questions

1. What are the dimensions of the paper sheet Size 24?
2. Where is the title block placed?
3. What does size designation 12 mean?
4. What is the length of dashes in a long chain line?
5. What determines the thickness of visible outlines?
6. What is the relation between the thickness of visible outlines and that of dimension and extension lines?
7. What is the difference in drawing centre lines for circles 50 mm dia. and 10 mm dia.?
8. How are parallel lines drawn using two triangles?
9. How is a line drawn perpendicular to a given line with the aid of two triangles?
10. How are parallel lines drawn at an angle of 20° to the edge of the drawing board using a T-square?
11. How many times is the height of capital letters greater than that of lower-case letters?
12. How is the capital letter *Д* spaced if preceded by the capital letter *Г*?
13. How is the letter *O* constructed?
14. How is a slant of 75° obtained by means of two triangles?
15. What determines the line thickness of letters and figures?

Exercise 1

Draw various lines with the aid of drawing instruments as in Fig. 32.

Exercise 2

Draw lines as in Fig. 33 on a standard sheet of paper Size 11.

Exercise 3

Construct all the letters (both capital and lower-case) of the Latin alphabet in lettering Size 10 using guide lines.

Letter several words in Size 3.5 lettering without guide lines.

II

GEOMETRICAL CONSTRUCTIONS

CHAPTER 1

PRINCIPAL GEOMETRICAL CONSTRUCTIONS

Of the numerous geometrical constructions, this chapter covers only those used in making engineering drawings.

1. DIVIDING STRAIGHT LINES INTO EQUAL PARTS AND CONSTRUCTING PERPENDICULARS

To divide a straight line into two and four equal parts. From the points *A* and *B* as centres and with a radius *R* greater than half the length of the given line describe two arcs intersecting at points *a* and *b* (Fig. 45*a*).

A line drawn through these points will divide the straight line *AB* into two equal parts at point *c*. The lengths *Ac* and *cB* are divided into two equal parts in the same manner, the straight line *AB* thus being divided into four equal parts.

A practical example of such dividing is given in Fig. 45*b*. Five equidistant slots are to be spaced on the plate. This is achieved by using the above method.

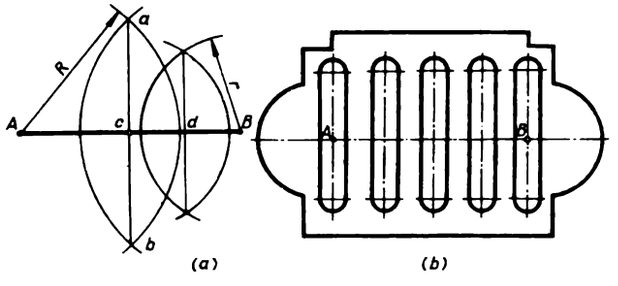


Fig. 45

To construct a perpendicular to a straight line from a point lying without it. From the given point *C* (Fig. 46) as a centre describe an arc of arbitrary radius to intersect the straight line *AB* at two points *D* and *E*. Now, with a radius *R* somewhat greater than half the length *DE*, from the points *D* and *E* as centres describe short arcs below the line *AB* which intersect at point *F*. Draw a straight line from the point *C* to the point *F* which will be the required perpendicular to the straight line *AB*.

To divide a straight line into any number of equal parts. Suppose it is necessary to divide the straight line *AB* (Fig. 47) into eleven equal parts. To this end proceed as follows.

Draw an auxiliary straight line *BC* at an acute angle to the given line *AB*. Mark off on it eleven equal sections of arbitrary length (points *1* through *11*). Join point *11* to point *A* with a

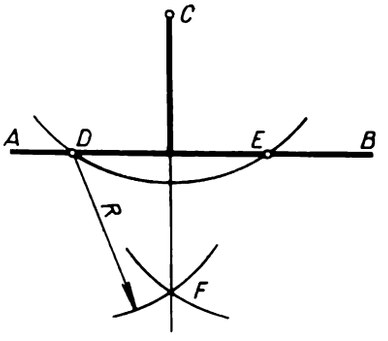


Fig. 46

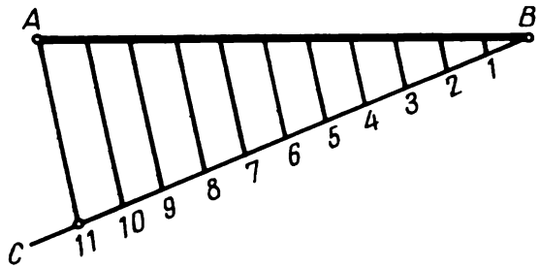


Fig. 47

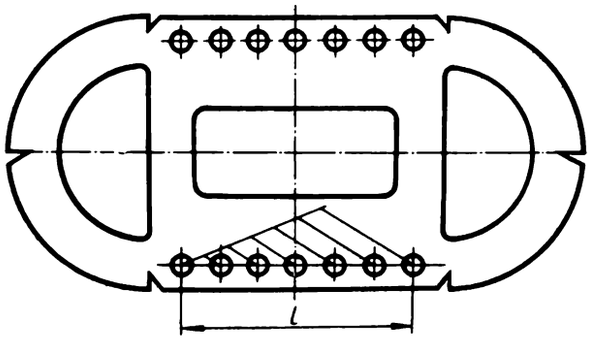


Fig. 48

straight line and, through points *10*, *9*, *8*, *7*, *6*, *5*, *4*, *3*, *2*, *1* draw (with the aid of a triangle and a ruler) ten more straight lines parallel to the line *11-A* which will divide the given line *AB* into eleven equal parts.

Using this method we can divide a straight line into any number of equal parts, as illustrated in Fig. 48. Shown in this figure is a templet where the centres of seven holes should be spaced equally over the length *l*.

2. CONSTRUCTING ANGLES AND DIVIDING THEM INTO EQUAL PARTS

Constructing angles. Angles are drawn with the aid of (1) a protractor, (2) one triangle and a ruler, (3) two triangles (one with angles of 45°, the other 60° and 30°) and a ruler. Fig. 49 illustrates the methods of drawing various angles by means of one (at *a*) and two (at *b*) triangles and a ruler. In this manner we can draw angles of 30°, 45°, 60°, 90°, 15° (60°−45°), 75° (45°+ +30°), 105° (60°+45°), 120° (180°−60°), 135° (180°−45°) and 150° (180°−30°).

To construct an angle to a straight line with the aid of a protractor, align the upper edge of its base with the straight line so that the centre of the protractor coincides with the vertex of the angle. Then find the required angle on the scale, mark a point with a pencil opposite the corresponding graduation and, finally, join this point to the vertex of the angle with a straight line. Fig. 50 illustrates the construction of the angle *BAC* equal to 55°.

To construct an angle equal to a given angle at a point on a given line. To transfer, or reconstruct, an angle equal to the given angle *BAC* (see Fig. 51*a*), use the given line A_1C_1 as one side of the required angle. With the vertex *A* of the given angle as a centre and any convenient length *R* as a radius, draw an arc across the given angle to intersect its sides at points *n* and *m* (Fig. 51*a*). With the same radius (now R_1) and from the point A_1 as a centre draw an arc which intersects line A_1C_1 at m_1. Set the compass from *m* to *n* on the original angle, and then with this radius and with m_1 as a centre describe a short arc intersecting the first arc at n_1. Draw straight line A_1B_1 through n_1 to complete the angle.

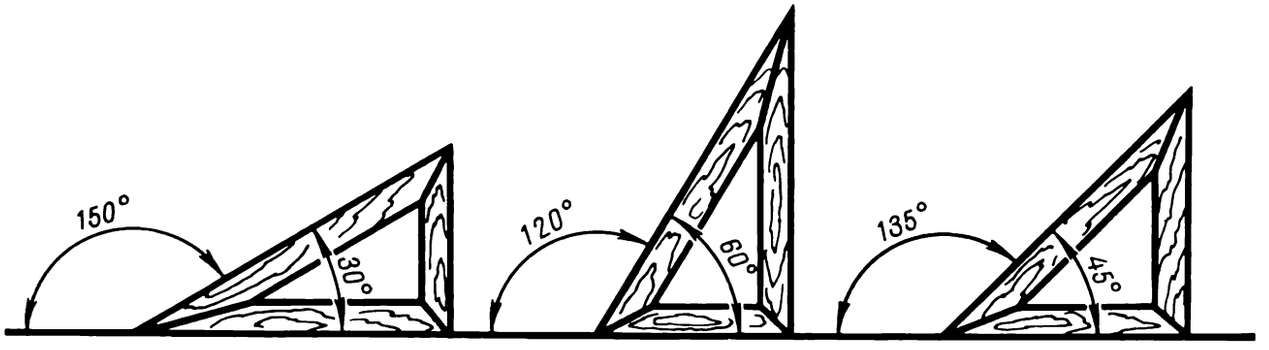
Fig. 52*a* shows a drawing of a templet, while Fig. 52*b* illustrates how two angles of its outline are transferred.

Constructing polygons. Outlines of mechanical parts are often polygons as, for example, in Fig. 53*a* presenting a plate with a hole cut in the shape of an irregular octagon, *1-8*. By measuring the lengths of the octagon's sides we can transfer or reconstruct it.

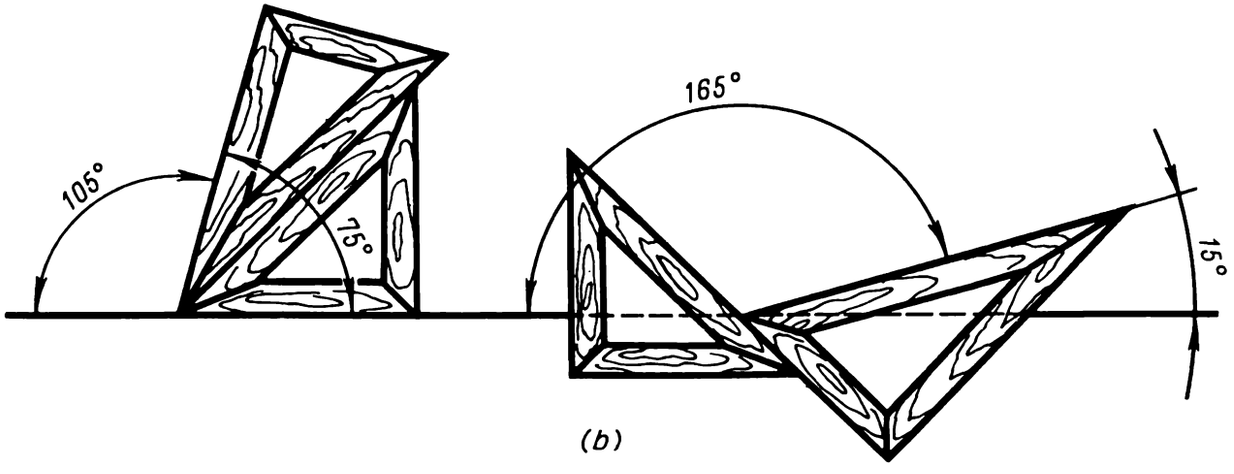
Any octagon may be divided into a series of triangles and the method of triangulation used. This consists of constructing a series of contiguous angles equal respectively to those in the triangles into which the original octagon is divided. In our example the triangles can be obtained by drawing diagonals *3-7*, *3-8* and *2-8* (Fig. 53*a*). They are reconstructed in the following succession.

Draw a vertical line and transfer to it the measured length 5_1-6_1 of the base *5-6* (Fig. 53*b*). Draw two horizontal lines through points 5_1 and 6_1 and transfer the lengths *5-4* and *6-7*, respectively. From the points 7_1 and 4_1, thus obtained, as centres and with radii equal to the diagonal *7-3* and the side *3-4*, respectively, describe two arcs to intersect at point 3_1 which will be one of the vertices of the required octagon. Proceeding in the same way we find vertex 8_1, then 2_1 and finally 1_1 taking as the base the lengths 3_1-7_1, 3_1-8_1 and 2_1-8_1, respectively.

Constructing angles with the aid of triangles



(a)



(b)

Fig. 49

In constructing polygons the *method of orthogonal coordinates* may also be used. In this case not the lengths of the polygon's sides but the coordinates of its vertices are measured. From the vertices of the octagon (points *1* to *8* in Fig. 53*a*) drop perpendiculars to the horizontal line *AB*. Draw a horizontal line of convenient length (Fig. 53*c*) and mark off on it the distances between the perpendiculars. At the points thus obtained erect perpendiculars to this line and transfer to them the corresponding distances between the line *AB* and the vertices (points *1* to *8*) of the original octagon (Fig. 53*a*).

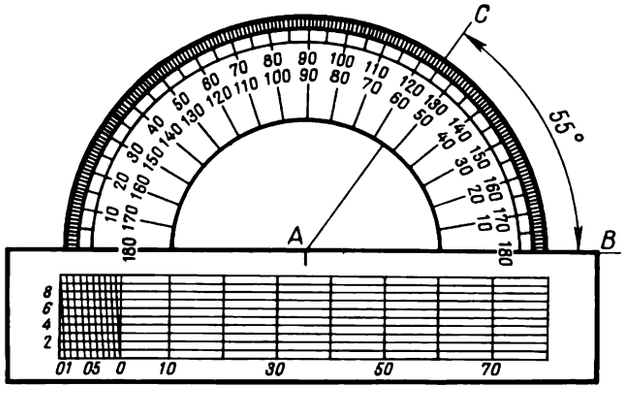
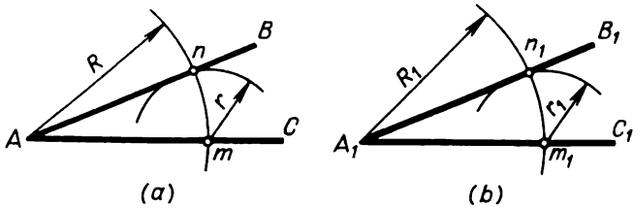


Fig. 50

To divide an angle into two equal parts. To divide angle *BAC* (Fig. 54) into two equal parts



(a) *(b)*

Fig. 51

or, in other words, to draw the bisector of this angle proceed as follows. With an arbitrary radius, from the vertex *A* describe an arc intersecting both sides of the angle at points *k* and *n*. From these points, with a radius of a somewhat greater length than half the arc *kn* describe two short arcs intersecting at point *m*.

From the vertex *A* of the angle draw a straight line to the point *m* which will divide the angle *BAC* into two equal parts, the line *Am* being its bisector.

By applying the foregoing method we can divide each half of the given angle (the angles *BAm* and *mAC*) into two equal parts, thus dividing the angle *BAC* into four equal parts.

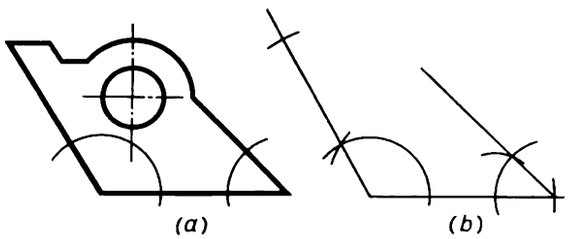


Fig. 52

Dividing a right angle into three equal parts. With an arbitrary radius *R* (Fig. 55), from the vertex *A* of the given right angle *BAC* as a centre describe an arc to intersect both sides of the angle at points *a* and *b*. With the same radius *R* and from the points *a* and *b* as centres describe two arcs intersecting the arc *ab* at points *m* and *n*. Now join these points with vertex *A* by straight lines *Am* and *An* which will divide the right angle *BAC* into three equal parts of 30° each. It is obvious that the angle *bAm* is equal to 60°, since $90°-30°=60°$. The angle *aAn* is also equal to 60° for the same reason.

A right angle can be divided into three equal parts with the aid of the 30°-60° triangle in the manner shown in Fig. 56.

In making drawings it is often necessary to divide a right angle into two equal parts. Fig. 57 shows how to do this in the simplest way.

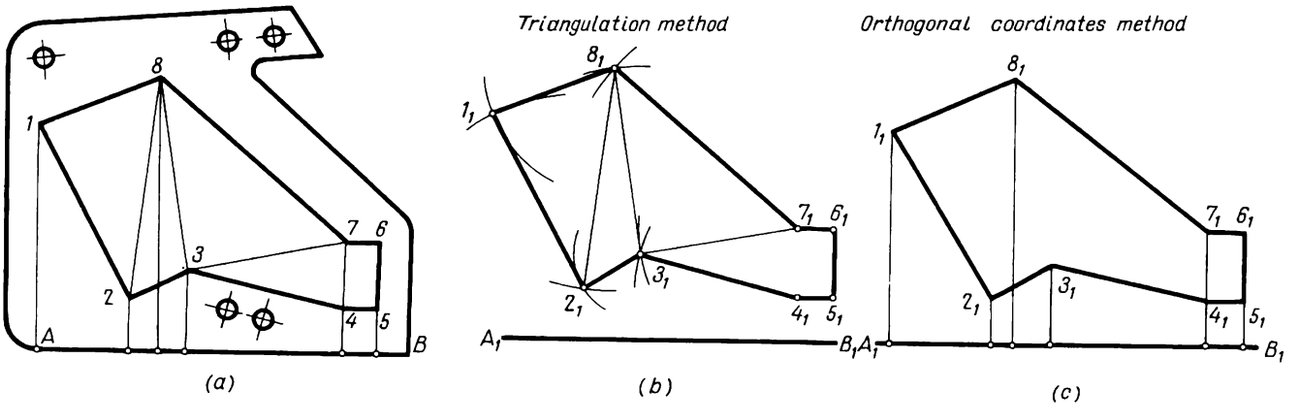


Fig. 53

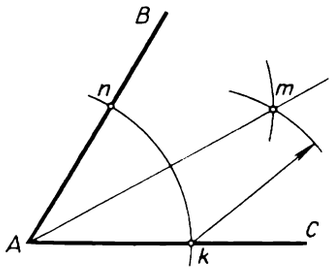


Fig. 54

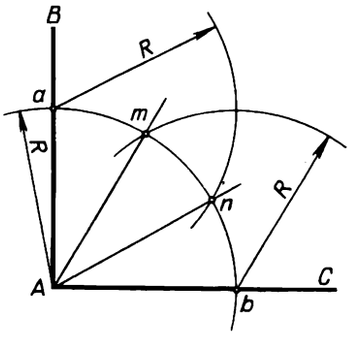


Fig. 55

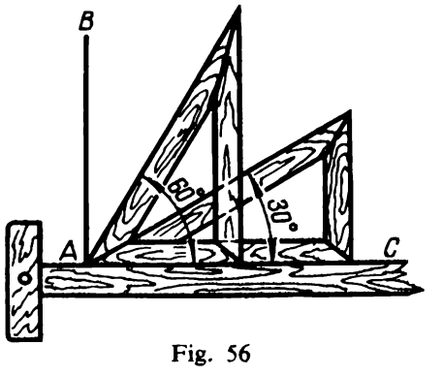


Fig. 56

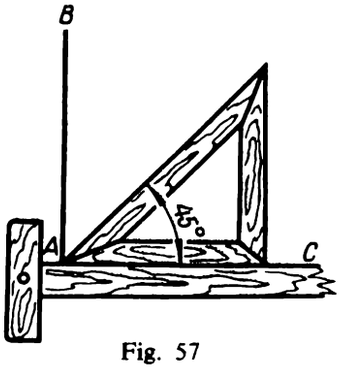


Fig. 57

Similar methods of dividing angles are widely employed in laying out steel sheets to cut various shapes.

3. FINDING THE CENTRE OF AN ARC

In making a drawing of a mechanical part we often deal with circles and arcs which constitute its outlines, and have to determine their radii and centres. Shown in Fig. 58*a* is a bracket whose rib has the shape of a concave arc.

To determine the centre and the radius of this arc, the latter should be first transferred to or traced on paper as shown in the figure. Then mark three arbitrary points, *A*, *B*, and *C*, on the arc and join them by two chords *AB* and *BC* (see Fig. 58*b*). Bisect each of them and draw perpendiculars through the middle of each chord. The centre of the arc will lie at the point *O* of intersection of these two perpendiculars (a radius perpendicular to the chord divides it into two equal parts; hence, a perpendicular drawn through a point at the middle of a chord is the radius of the arc). This means that *OA* is the radius of the arc *ABC*.

4. CONSTRUCTING SLOPES AND TAPERS

In making drawings of certain profiles of rolled steel (I-beam shown in Fig. 59 at *a* and a channel at *b*) we often have to draw inclined lines which are specified either by the angle of slope or by the so-called *gradient*. The gradient (designated as *i*) is defined as the ratio of the leg *AC* opposite angle α to the leg *BC* (see Fig. 60*a*), in other words, the gradient of the straight line *AB* is the ratio of its elevation (the vertical side *AC*) to its horizontal projection (the horizontal side *BC*), i.e., it is equal to tan α. Gradients may be expressed in degrees or per cent, as a ratio of two numbers (1:6), or as a fraction.

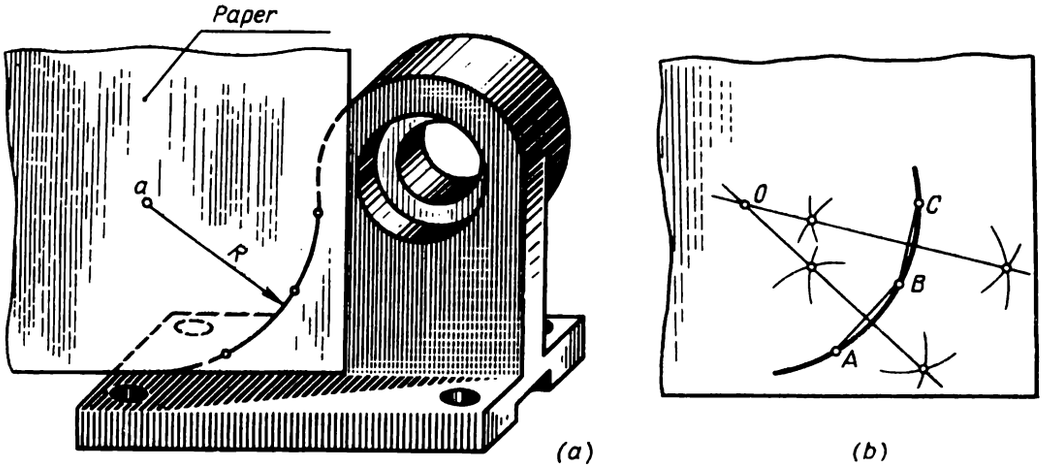


Fig. 58

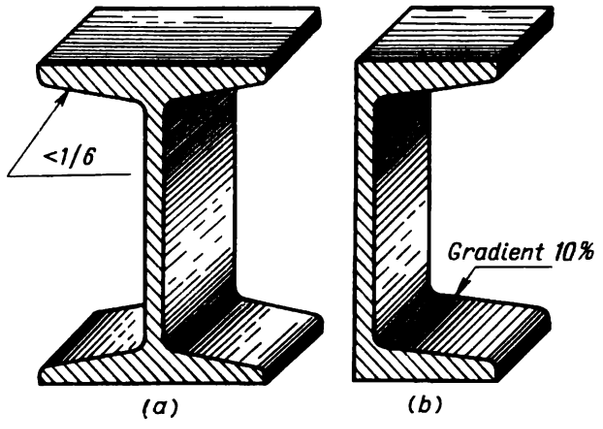


Fig. 59

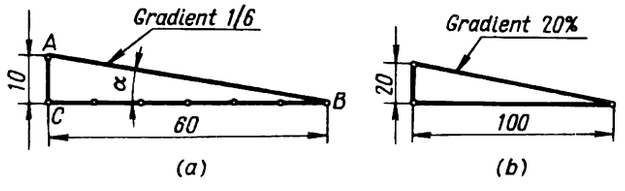


Fig. 60

In Fig. 60*a* the gradient is expressed as a vulgar fraction.

$$i=\tan\alpha=\frac{AC}{BC}=\frac{1}{6}$$

In order to obtain a straight line with a given gradient, say, $i=1:6$ (Fig. 60*a*) draw a horizontal line *(BC)* and mark off six equal arbitrary units on it. Draw a perpendicular to the point *C* and mark off one such unit *(CA)* on it. Join the points *A* and *B* thus obtaining the inclined line *AB* with a gradient 1:6.

In drawing the outline of the flange of an I-beam (Fig. 59*a*) with a specified gradient 1:6 proceed as follows: first construct a gradient triangle to obtain an inclined line and then draw the required outline parallel to this line.

If the gradient is given in per cent, say, 20 per cent (Fig. 60*b*), the inclined line is constructed using the foregoing method, i.e., as the hypotenuse of a right-angled triangle one side of which is equal to 100 mm, and the other to 20 mm.

In drawing the outline of a channel with a gradient of 10 per cent (Fig. 59*b*) begin with constructing an inclined line parallel to the obtained hypotenuse.

According to the USSR Standard the inscription "Gradient 20%" should be located above a leader line parallel to the horizontal side of the gradient triangle; the distance between the inscription and the leader should be approximately equal to the height of the lettering. Instead of the word "Gradient" the symbol $>$ may be used which should be pointed in the direction of slope.

In constructing angles gradient triangles are widely used.

Table 4 gives the values of gradients in per cent for various angles (up to 45°).

Taper is usually defined as the ratio of the diameter of the base of a right cone to its height. In a truncated cone the taper k is expressed by the ratio of the difference of its bases $(D-d)$ to its height H: $k=\frac{D-d}{H}$, or in per cent: $k=\frac{D-d}{H}100\%$.

According to the standard the number specifying the taper must be preceded by the conventional symbol for taper which is a small triangle pointing toward the vertex of the cone (see Fig. 61*a*). According to the same standard this symbol may be substituted by the inscription "Taper" which is to be lettered parallel to the cone axis, inside or outside the cone (Fig. 61*b*).

A drawing of a truncated cone usually specifies the larger base diameter (Fig. 61*a*), since in manufacturing a tapered part this diameter can be measured much more easily and accurately.

As a rule, taper is indicated on drawings of such mechanical parts as the tailstock centre (Fig. 61*c* and *d*) or of cutting tools (shanks of drills, reamers, milling cutters, etc.).

Table 4

Angle in degrees	4	5	6	7	8	10	12	15	20	30	35	40	41	45
Gradient in per cent	7	8.7	10.5	12.3	14.0	17.6	21.3	26.8	36.4	57.7	70.0	83.9	86.9	100.0

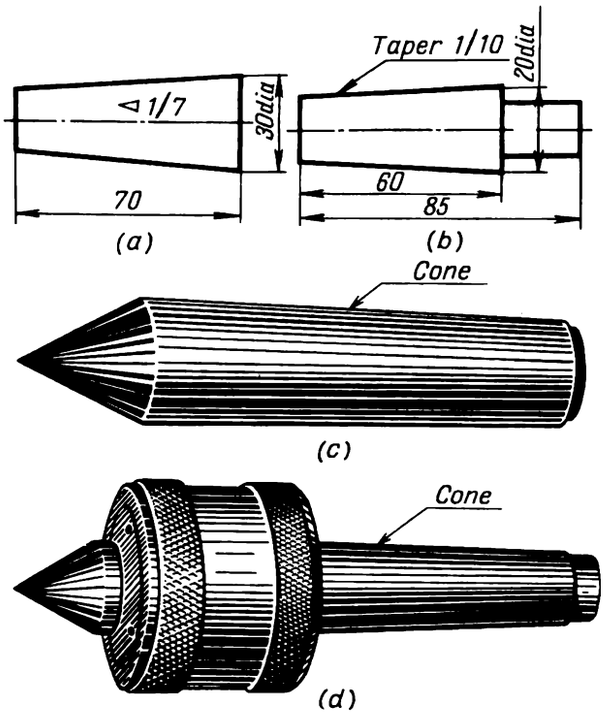


Fig. 61

Below is an example in constructing the outlines of an object having the shape of a truncated cone with a given taper.

Suppose it is required to construct the outlines of the upper (spool) and lower (bearing) tapered portions of the spindle of a spinning frame (Fig. 62).

1. Numerical values given for constructing the upper (spool) part of the spindle: $k_1=2.5\%$; $H_1=120$ mm; $D_1=7.5$ mm.

Draw the centre line, mark off the given height of the cone ($H_1=120$ mm) and diameter ($D_1=7.5$ mm), see Fig. 62.

Using the formula

$$k_1=\frac{D_1-d_1}{H_1}\,100$$

determine the numerical value of d_1

$$d_1=\frac{100D_1-k_1H_1}{100}=\frac{(100\times7.5)-(2.5\times120)}{100}$$

$$=\frac{750-300}{100}=4.5 \text{ mm}$$

Now mark it off at the left, perpendicular to the centre line, and join the ends of the diameters D_1 and d_1 to complete the truncated cone.

2. Numerical values given for constructing the lower (bearing) part of the spindle: $k_2=5\%$; $H_2=50$ mm; $D_2=7$ mm.

In this case

$$d_2=\frac{100D_2-k_2H_2}{100}=\frac{(100\times7)-(5\times50)}{100}$$

$$=\frac{700-250}{100}=\frac{450}{100}=4.5 \text{ mm}$$

The construction is as before.

Questions

1. How is a straight line divided into any number of equal parts?
2. Explain the method of triangulation.
3. How is a polygon constructed equal to the given one using the method of orthogonal coordinates?
4. How are the centre and radius of an arc determined in the outlines of a mechanical part?
5. What is the difference between gradient and taper?

Exercise 4

1. Divide the straight line *AB* into four equal parts.

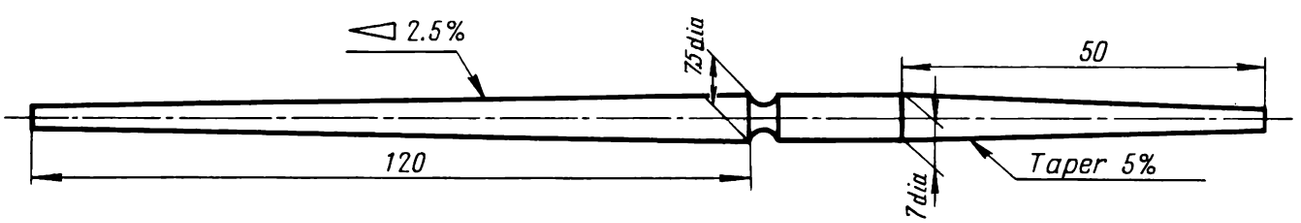


Fig. 62

2. Divide the straight line *AB* into any number of equal parts.

Exercise 5

1. Draw several angles with the aid of triangles and a protractor.
2. Draw an angle equal to a given angle.
3. Draw a polygon equal to a given one using the method of triangulation and the method of orthogonal coordinates.

Exercise 6

1. Divide angles into equal parts with the aid of a compass and a triangle.
2. Find the centre of a given arc.

Exercise 7

1. Construct gradients 1:2, 1:5, and 14%.
2. Draw a truncated cone having $H=100$ mm, $D=40$ mm, and $k=10\%$.

CHAPTER 2

SCALES AND DIMENSIONING

1. SCALES

It is desirable to make full-size drawings of machine parts and assemblies in order to represent their true shape and dimensions.

Large objects of comparatively simple shape are drawn in less than full size; on the other hand, small objects (such as watch parts) are scaled up.

The *scale* is the relation between the dimensions of the drawing of an object and the actual dimensions. Scales should be selected according to the standard. Tabulated below are the scales used in mechanical drawings.

All drawings should be made to scale and the scale used stated on the drawing. The accepted abbreviations are:

Scale 1/1 (for full size)

Scale 1/4 (for quarter size)

Scale 2/1 (for twice full size), and so on.

If a part is drawn full size (Fig. 63*b*) and a drawing twice full size of the same part is needed, use should be made of the *angular (proportional) scale* which is constructed as follows (Fig. 63*a*). Draw a straight line in any direction. Then from the point *O* as a centre and with a radius $R=100$ mm describe an arc to intersect the given line at the point *A*. From this point and with a radius $R_1=50$ mm draw another arc which will intersect the first arc at the point *m*.

Now join the points *m* and *O* with a straight line to complete the angular scale. It is used in the following way. From the centre *O* draw arcs with the radii equal to the dimensions of the part, then the chords of these arcs will be equal to half the respective dimensions. For example, the length *kn* is equal to $0.5c$, and so on.

Table 5

Scales Established by the USSR Standard

Reduction scales											
1:2	(1:2.5)*	(1:4)	1:5	1:10	(1:15)	1:20	(1:25)	1:40	1:50	(1:75)	1:100

Full size	Magnification scales							
1:1	2:1	(2.5:1)	4:1	5:1	10:1	20:1	40:1	50:1

* The scales given in parentheses are permitted but not recommended.

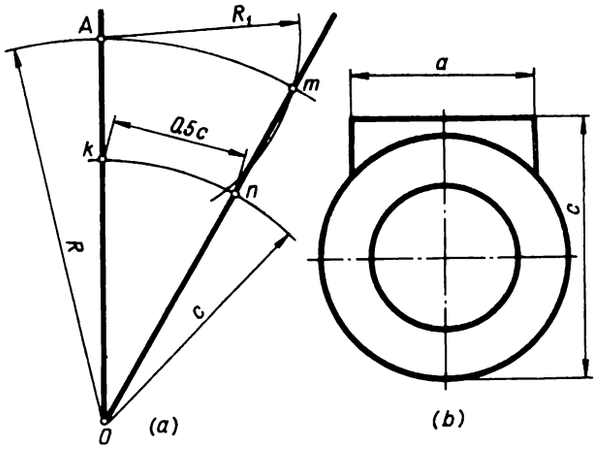


Fig. 63

With scale 1/5, the radius $R_1=\frac{R}{5}=\frac{100}{5}=$ $=20$ mm; with scale 1/2.5, the radius $R_1=$ $=\frac{R}{2.5}=\frac{100}{2.5}=40$ mm, etc.

2. DIMENSIONING

Working drawings must indicate all the necessary dimensions in a way most convenient for the workman.

The size of the object or its separate parts is usually indicated in drawings by means of dimension lines, complete with figures showing the actual measurement irrespective of the scale. As a rule, dimensions in machine drawings are given in millimetres without adding the abbreviation mm.

Dimension lines are made with fine continuous lines, so as to contrast with the heavier outline of the drawing. They are drawn parallel to the sections whose length they indicate and are terminated by carefully made arrowheads at the ends of the dimension line.

Dimension figures must be written clearly and neatly to avoid confusion and possible errors. They should be written above and parallel to the dimension line and as close to its centre as possible (Fig. 64*a*).

The figures may also be inserted in a gap in the dimension line. If a view has a break, however, the dimension line must be drawn without a gap, as in Fig. 65*d*.

Each dimension in a drawing must be given only once; duplicate dimensions should be avoided.

Dimension lines are preferably (but not obligatory) drawn outside the drawing outlines. Avoid intersection of extension and dimension lines.

When a series of parallel dimension lines are in close proximity to one another, the dimensions should be staggered, as shown in Fig. 64*a*. Centre lines and cross-hatching lines must be broken where figures are to be placed (see Fig. 64*a*).

Dimension lines must not be the continuation of outlines, axial, centre or extension lines. On the other hand, the outlines, axial, centre and extension lines must not be used as dimension lines.

Arrowheads terminating the dimension lines must just touch the corresponding outlines, or centre lines, or extension lines. The size of arrowheads depends on the thickness of visible outlines and must be one and the same for all dimension lines of a given drawing. Arrowheads should be made as shown in Fig. 65*a*.

Extension lines must extend 2 to 5 mm beyond the ends of the arrowheads.

If there is not enough space for an arrowhead because two lines of the visible outline are too close to each other, one of the lines may be broken (see Fig. 64*a*, dimension 64 and Fig. 66*b*, dimension 10).

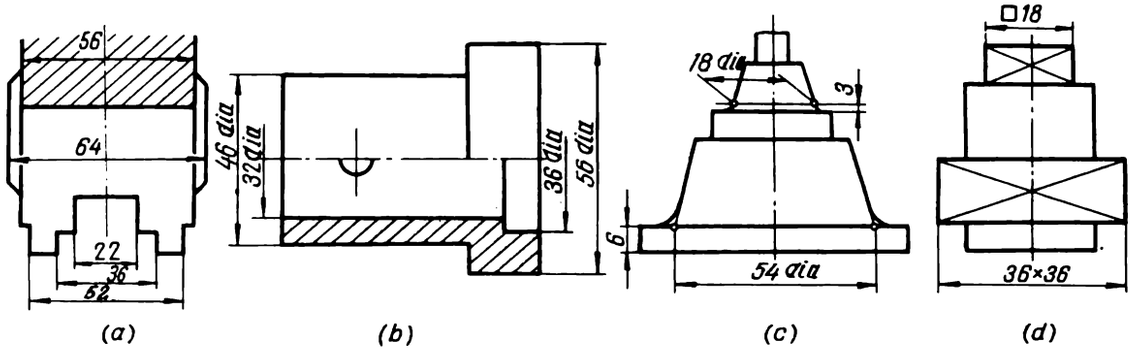


Fig. 64

When dimensioning very narrow spaces do as shown in Fig. 64*c* (dimensions 6 and 3) or as in Fig. 65*b* (dimensions 3, 2 and 3). As is seen from the latter figure, if there is no room for arrowheads at the ends of dimension lines arranged in a continuous chain, they may be replaced by dots.

On half-sectioned views with an axis of symmetry it is permissible to dimension as in Fig. 64*b* (dimensions 32 dia and 36 dia). In this case the dimension line must extend somewhat beyond the axis of symmetry.

Squares (or square holes) are dimensioned in the following manner: 36×36, where 36 is the dimension of the side, or the dimension is preceded by a small square, for example, □ 18 (see Fig. 64*d*).

For a circle the diameter is the only essential dimension. The diameter, not the radius, should always be given for a circle, since this is the dimension the workman will use whether he is turning a cylinder on a lathe or drilling a hole. The correct method of placing dimension lines and numerals for diameters is shown in Fig. 66*a-d*.

When dimensioning a number of equi-spaced similar elements of a machine part, say, holes, proceed as in Fig. 66*c* (usually only one hole is dimensioned and the number of holes indicated).

Fig. 67*a* illustrates dimensioning circular arcs, while Fig. 67*b* shows how spherical surfaces are dimensioned.

A 45-degree chamfer is dimensioned using a dimension line (as in Fig. 65*d*). The figure is the linear dimension of the side of the right triangle formed by the chamfer. Chamfers cut at other angles are dimensioned according to the general rules: either with the linear dimensions of the two triangle legs, or with one linear and one angular dimension.

Fig. 68*a* and *b* shows the recommended practice for placing angular dimensions.

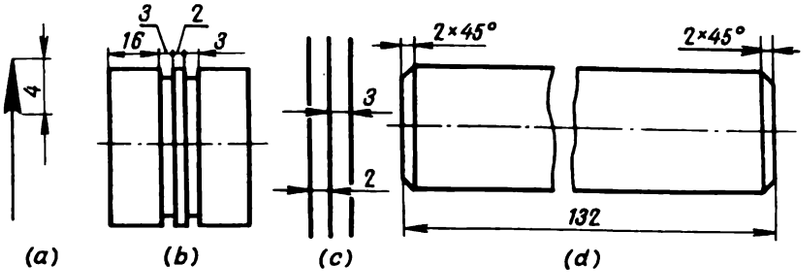


Fig. 65

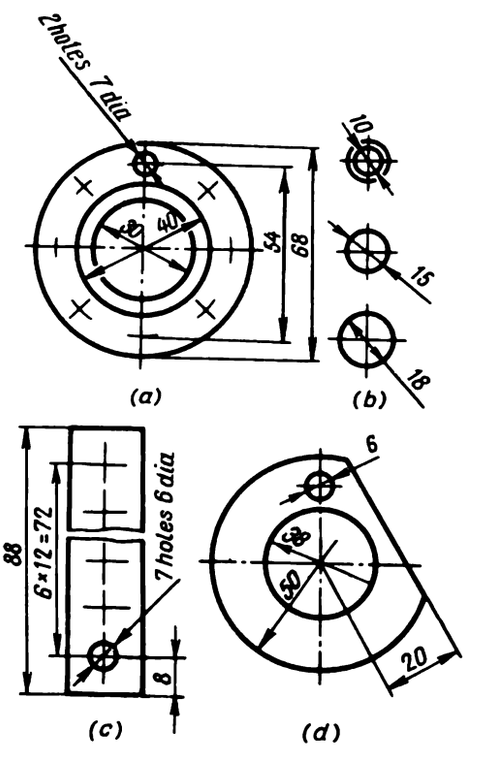


Fig. 66

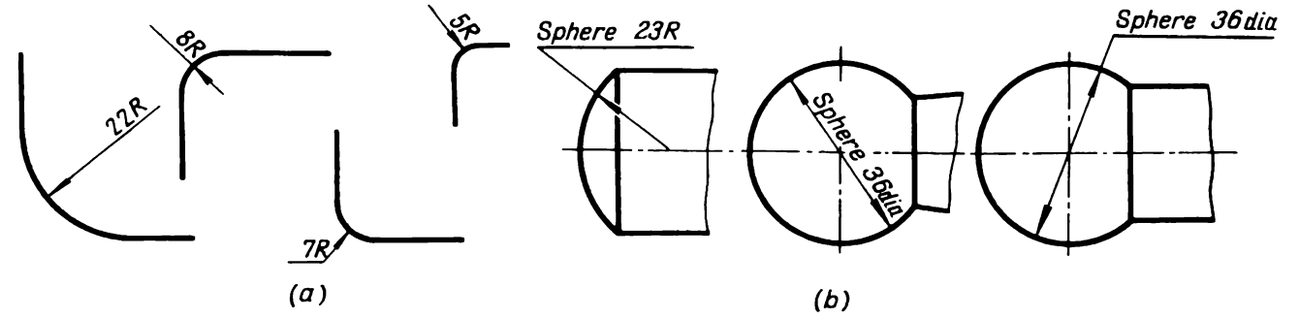


Fig. 67

Extension lines should be perpendicular to the dimension lines. In certain cases, by way of exception, extension lines may be drawn not at a right angle to dimension lines, but as is shown in Fig. 64*c* (dimension 18 dia). In this case the extension lines must be parallel to each other.

In cases such as shown in Fig. 64*c* (dimension 54 dia) the extension lines are drawn from the points of intersection of the continuations of the visible outlines.

The coordinates of points on a non-circular curve may be indicated by dimension lines drawn as in Fig. 68*c*.

Where space limitations do not permit giving a separate line for each dimension, the dimensions may be placed in one line as shown in Fig. 69*b* and *c*. In this method, called progressive (or consecutive) dimensioning, there is only one arrow for each dimension, thus indicating that each dimension goes back to the original base line, say zero.

For more detail see the USSR Standard *Dimensioning*.

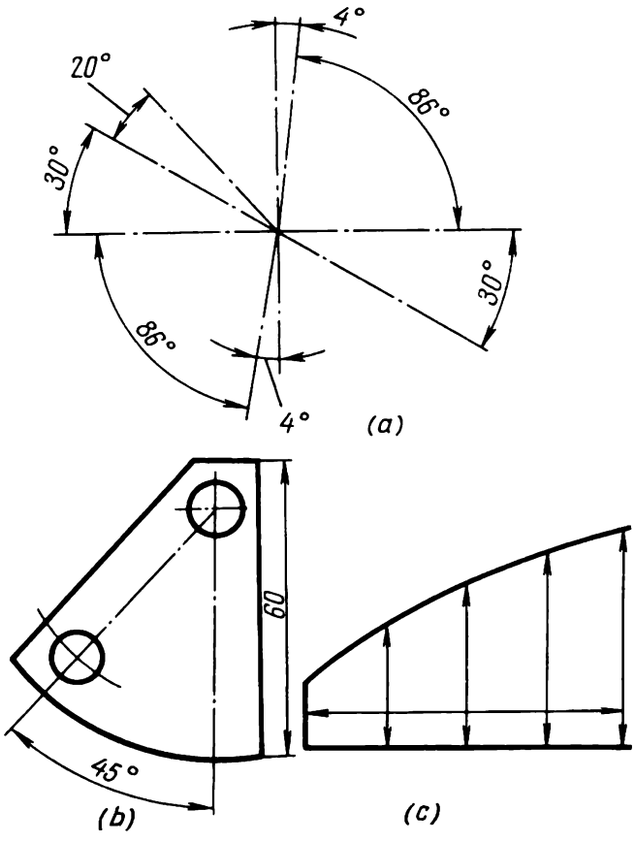


Fig. 68

Questions

1. What scales are established by the USSR Standard?
2. How is a full-size drawing of a machine part reduced to half full size making use of the angular (proportional) scale?
3. What are the rules for relative positioning of extension lines and dimension lines?
4. How are the dimension figures located?
5. What are the notations for the radius and the diameter?
6. What is the recommended practice of drawing dimension lines when one line of the visible outlines gradually merges into another through an arc?
7. How are angles dimensioned?

Exercise 8

Construct a 1/2.5 angular scale.

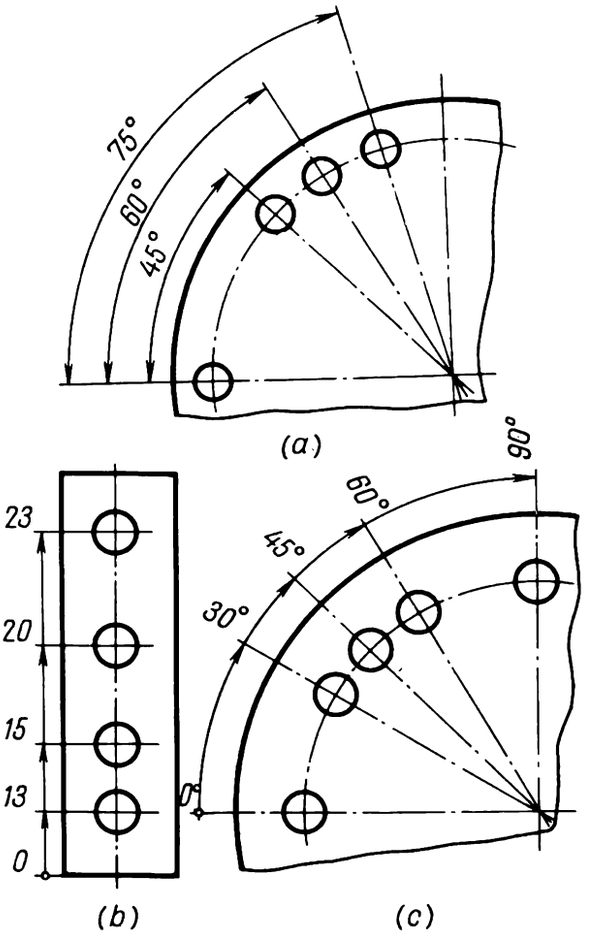


Fig. 69

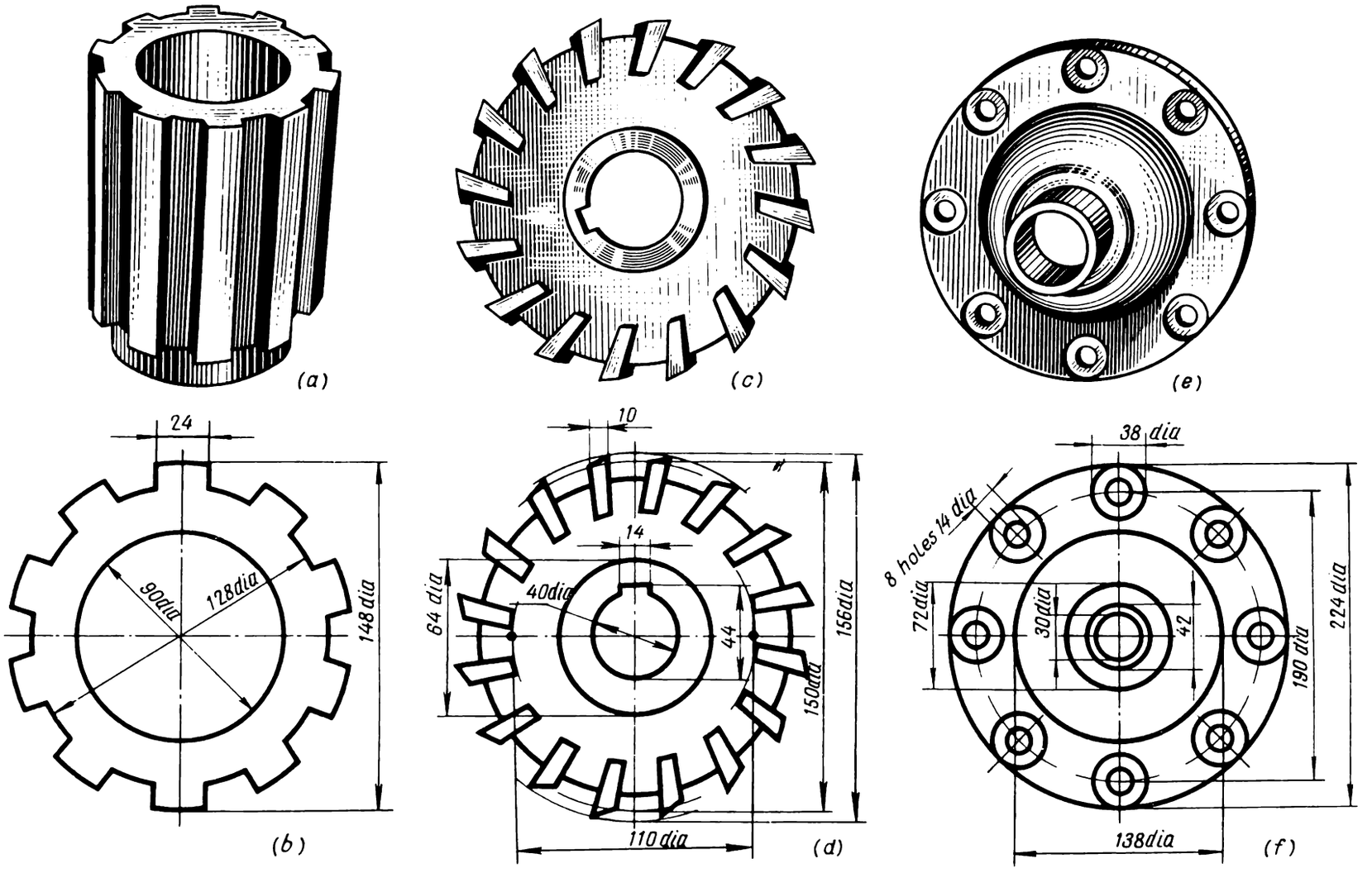

(a)
(c)
(e)
24
90dia
128dia
148dia
(b)
10
14
40dia
64 dia
44
150dia
156dia
110dia
(d)
38 dia
8 holes 14 dia
72dia
30dia
42
190 dia
224dia
138dia
(f)

Fig. 70

CHAPTER 3

DIVIDING A CIRCLE INTO EQUAL PARTS

In making drawings of machine parts sometimes it is necessary to divide a circle into equal parts.

On learning the rules the student must do a number of exercises, but first the actual machine parts to be drawn should be examined thoroughly.

Presented in Fig. 70 are several parts requiring the division of a circle into equal parts.

A sleeve with ten slots is shown in Fig. 70*a* and its plan view in Fig. 70*b*. To draw this view the circle 128 dia (or 148 dia) has to be divided into ten equal parts.

Fig. 70 shows a milling cutter (at *c*) and its plan view (at *d*). In drawing the cutter the circle 156 dia has to be divided into 16 equal parts.

The lid shown in Fig. 70*e* and *f* has eight equi-spaced holes 14 dia and counterbores 38 dia. To draw these holes the circle 190 dia has to be divided into eight equal parts.

1. DIVIDING A CIRCLE INTO FOUR OR EIGHT EQUAL PARTS

To draw the outlines of the lid shown in Fig. 71*a* it is necessary to divide the circle into eight equal parts in the following way. First draw two mutually perpendicular axes, horizontal and vertical (Fig. 71*b*), to intersect at point *O*. Then from the point *O* as a centre describe a circle on which the eight holes are to be spaced. The points of intersection *(1, 3, 5, 7)* of the circle with the horizontal and vertical axes will divide the circle into four equal parts.

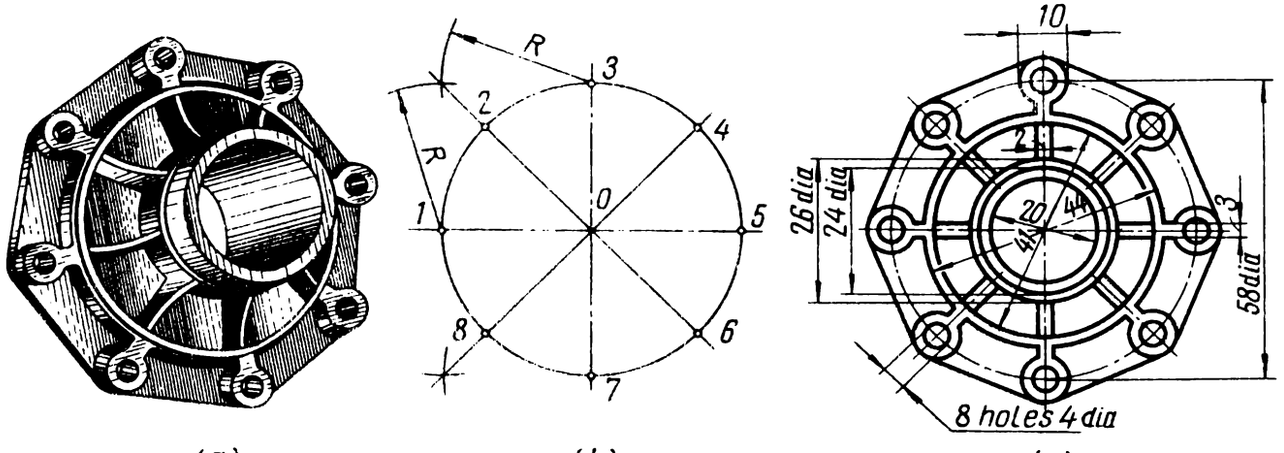
Points *2*, *4*, *6*, and *8* are obtained with the aid of a compass. Point *2*, for example, is on a line through the arbitrary radius *R* (somewhat longer than half the chord *1-3*) described from points *1* and *3* as centres.

A circle can be divided into four and eight equal parts also by means of a 45°-45° triangle (see Fig. 72*b*). The flange in Fig. 72*a* and *c* has four equi-spaced holes and eight radial slots.

When dividing a circle into four or eight equal parts with the aid of a triangle, the lines drawn along its hypotenuse must pass through the centre of the circle.

2. DIVIDING A CIRCLE INTO THREE, SIX AND TWELVE EQUAL PARTS

To divide a circle into three and six equal parts. The lid shown in Fig. 73*a* has three equi-spaced holes. In drawing its outlines (Fig. 73*c*) the circle 64 dia must be divided into three equal parts, which is done by means of a compass (see Fig. 73*b*). From *A* as a centre and with a radius equal to that of the given circle draw an arc which will intersect the given circle at points *2* and *3*. Points *1*, *2*, and *3* divide the circle into



(*a*) (*b*) (*c*)

Fig. 71

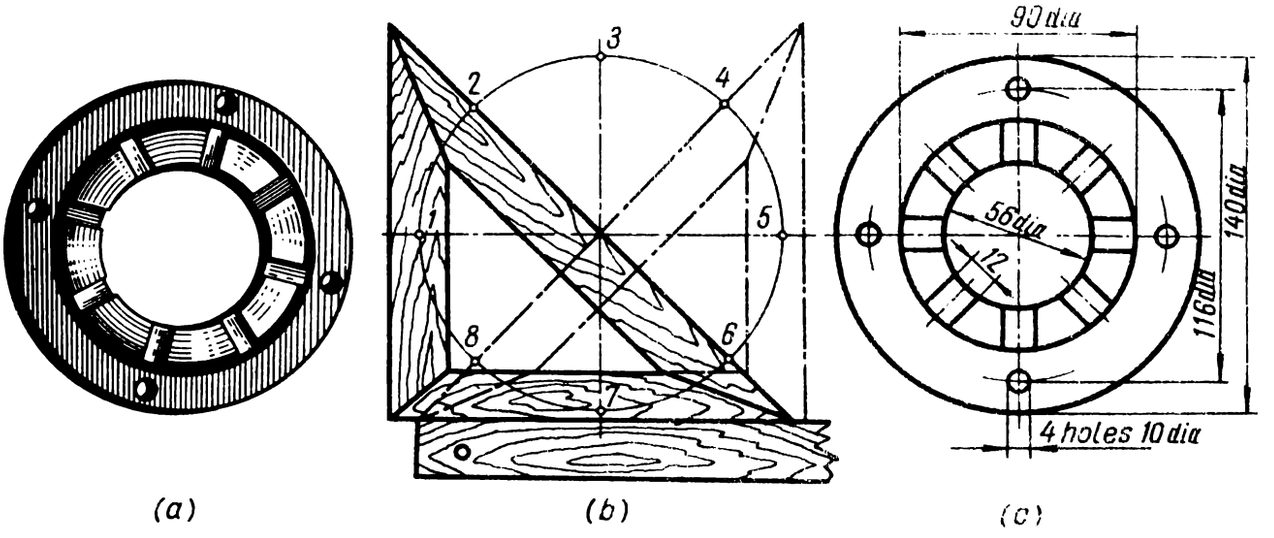


Fig. 72

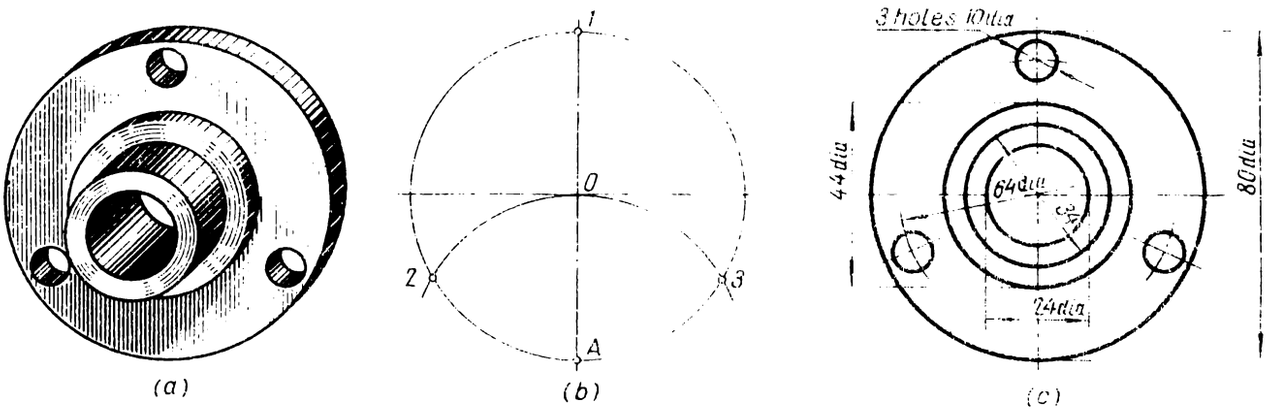


Fig. 73

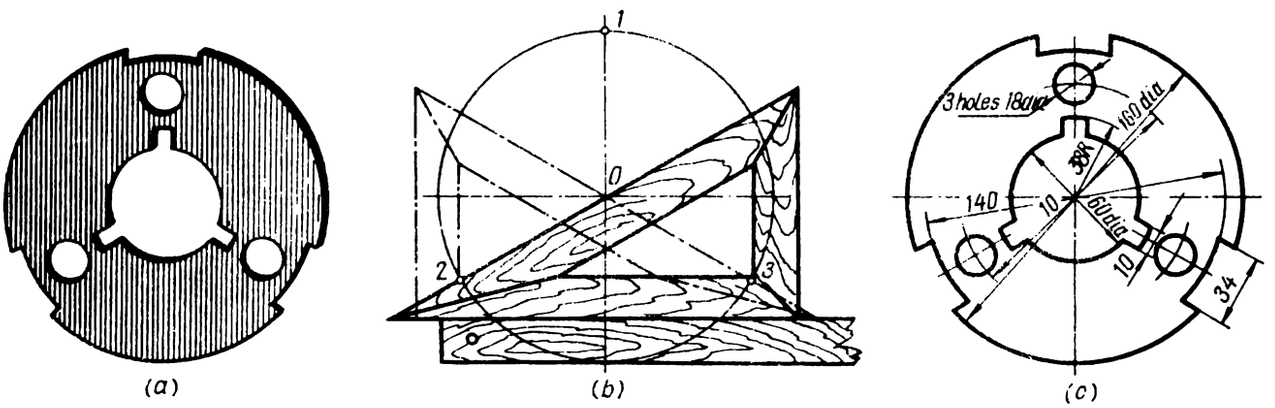


Fig. 74

three equal parts. The same result can be obtained by making use of a 30°-60° triangle, as illustrated in Fig. 74*b*. The dividing lines drawn along the hypotenuse of the triangle must pass through the centre of the given circle.

The disk shown in Fig. 75*a* has six equispaced recesses and six holes. Fig. 75*b* illustrates how to divide a circle into six equal parts with a compass. Here we apply the same method as in Fig. 73*b*, the only difference being that two arcs are described: from points *1* and *4* as centres. The identical result can be obtained by making use of a 30°-60° triangle (see Fig. 76*b*). Make sure that the dividing lines pass through the centre of the circle.

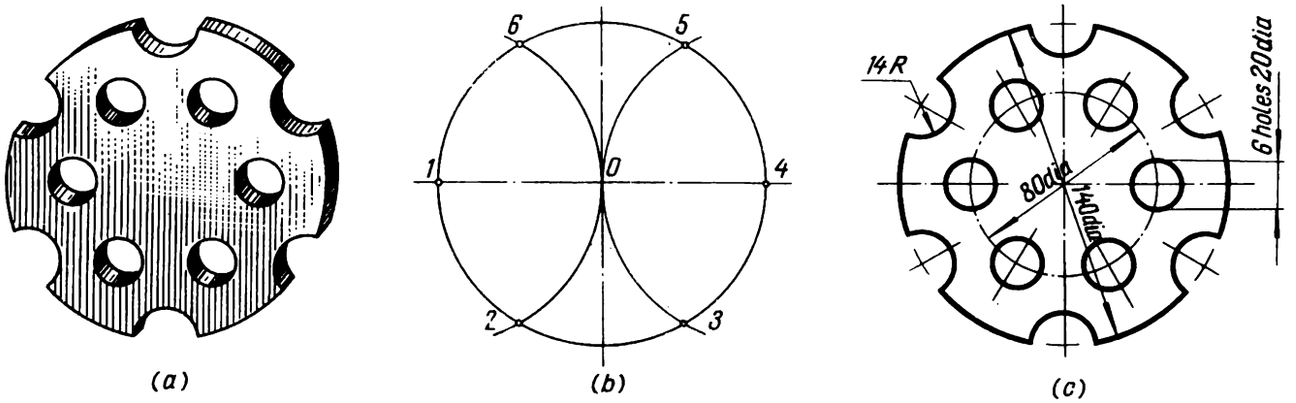
To divide a circle into twelve equal parts. Shown in Fig. 77*a* is a hexagonal castle nut with equispaced slots arranged against the middle of each side of the hexagon. To draw the nut, describe a circle and divide it into six equal parts using a 30°-60° triangle as above (see Fig. 77*b*). Then divide the circle into twelve equal parts by placing the shorter leg of the same triangle against a ruler as indicated in Fig. 77*b* by the dot-and-dash lines.

Fig. 77*c* is the plan view of the nut.

3. DIVIDING A CIRCLE INTO FIVE AND SEVEN EQUAL PARTS

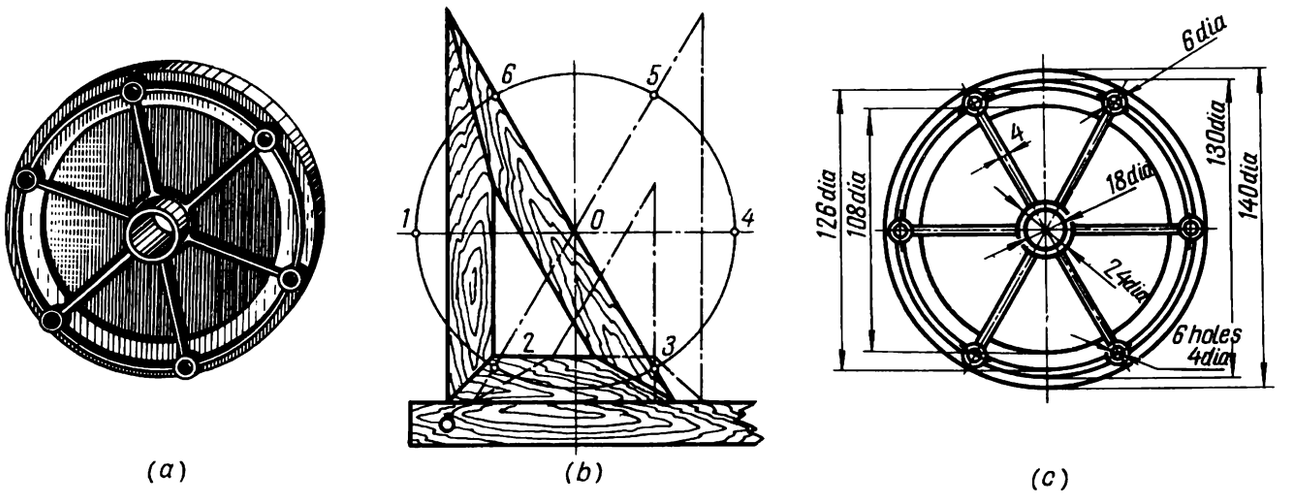
To divide a circle into five equal parts. Shown in Fig. 78*a* is a threading die. To draw its outlines (Fig. 78*c*) a circle has to be divided into five equal parts. Proceed as follows (Fig. 78*b*).

First draw the axes, then from the point *O* as a centre describe a circle of the given dia-



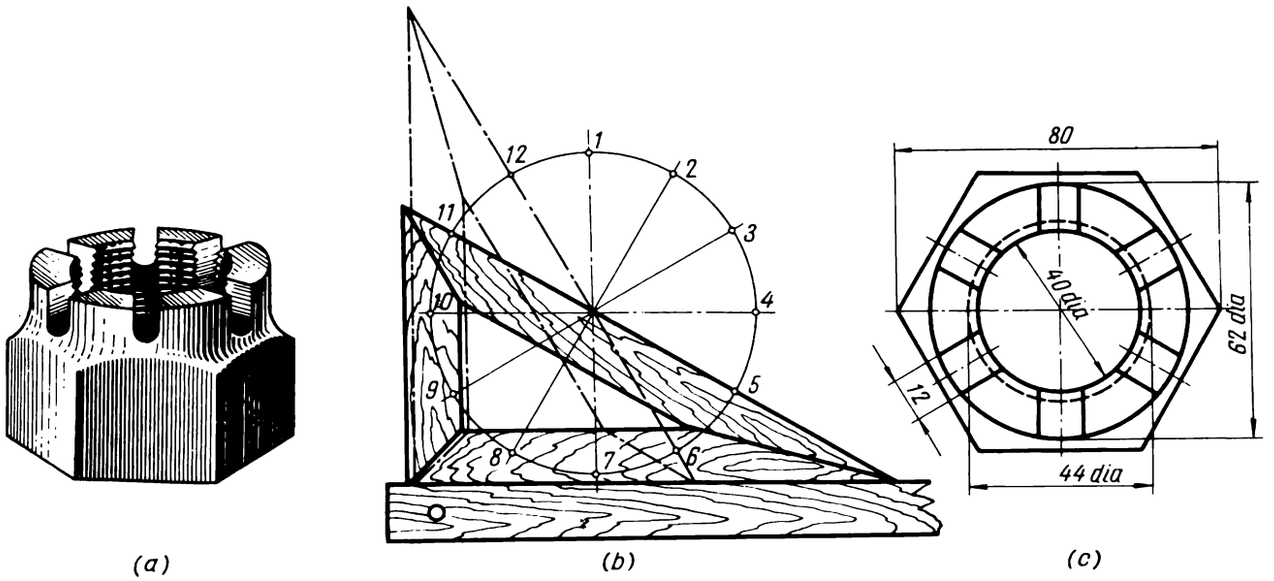
(*a*) (*b*) (*c*)

Fig. 75



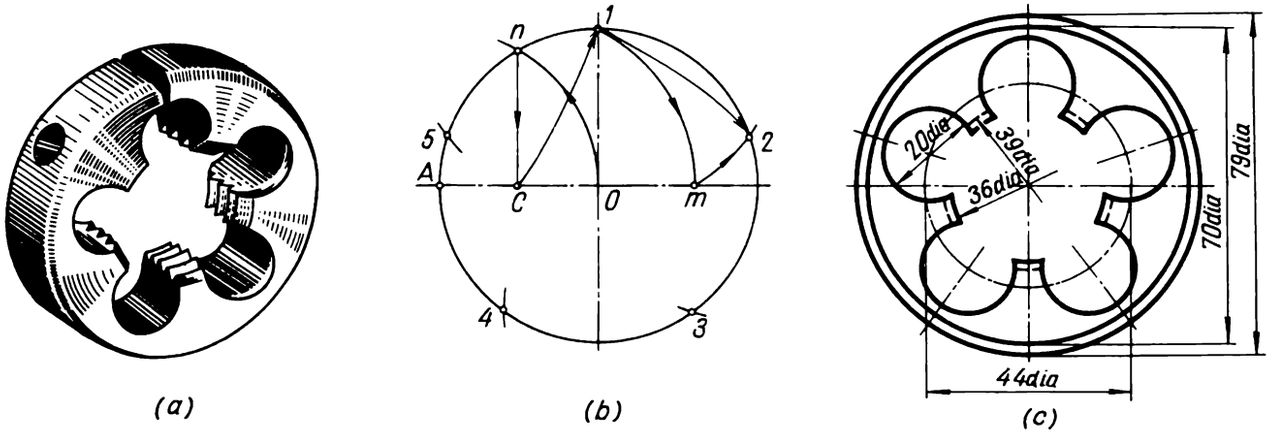
(*a*) (*b*) (*c*)

Fig. 76



(a) (b) (c)

Fig. 77



(a) (b) (c)

Fig. 78

meter (44 dia). From the point *A* as a centre and with a radius equal to the radius of the given circle draw an arc to intersect the circle at point *n*. From this point drop a perpendicular to the horizontal axis. From the point *C* thus obtained and with a radius equal to the length *C1* describe an arc to intersect the horizontal axis at point *m*. Now from the point *1* as a centre and with a radius equal to the length *m1* draw an arc to intersect the circle at point *2*. The latter is the second required point, point *1* being the first. The rest of the points, dividing the circle into five equal parts (points *3*, *4* and *5*), are found by setting the compass to the length *1-2* and marking off on the circle.

To divide a circle into seven equal parts. The castor shown in Fig. 79*a* has seven equi-spaced holes (dia. 18) with their centres lying on a circle dia. 66.

To draw the castor holes (Fig. 79*c*) proceed as follows (Fig. 79*b*).

Draw the axes. From the point *O* as a centre and with the given radius 33*R* describe a circle.

From the point *A* as a centre and with the same radius draw an arc to intersect the circle at point *n*. From point *n* drop a perpendicular

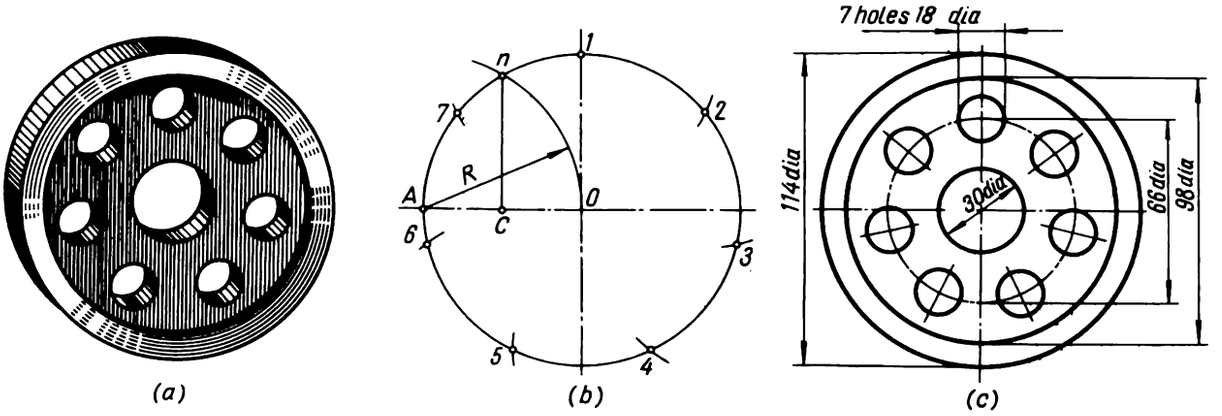


Fig. 79

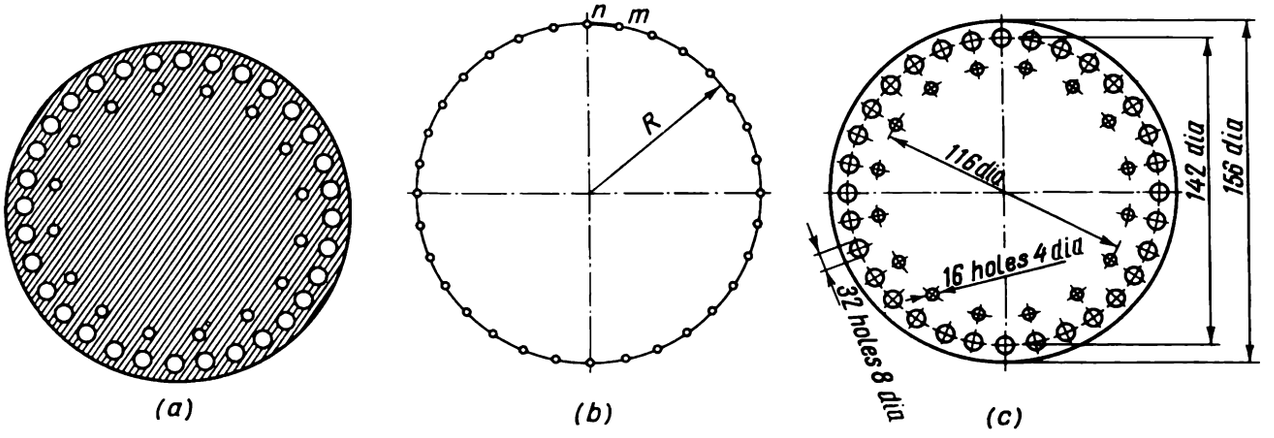


Fig. 80

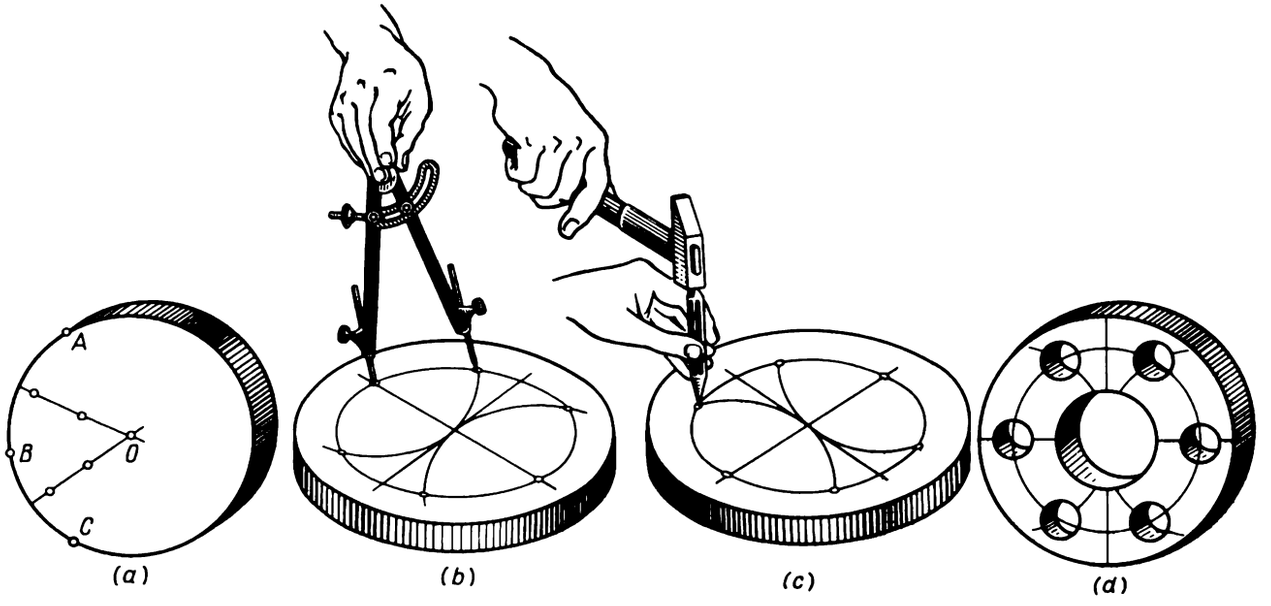


Fig. 81

to the horizontal axis to intersect it at point *C*. Set the compass from *n* to *C* and from point *1* mark off this length on the circle to obtain the required points *2*, *3*, *4*, *5*, *6*, and *7*. This is only an approximate method.

4. DIVIDING A CIRCLE INTO ANY NUMBER OF EQUAL PARTS

In dividing a circle into any number of equal parts we can use the table of factors (see Table 6).

Knowing the number of parts *n* into which the circle is to be divided we take the corresponding factor *k* from the table. By multiplying the factor *k* by the diameter *D* of the circle we find the length *l* of the chord which should be marked off on the circle and will serve to divide it into *n* equal parts.

Fig. 80*a* shows a disk. In drawing its outlines (Fig. 80*c*) the circle dia. 142 has to be divided into 32 equal parts.

This is done by making use of the above table.

The factor *k* corresponding to $n=32$ will be $k=0.09802$. Now we determine the length of the required chord: $l=D\times k=142\times 0.09802=$ $=13.9$ mm. Set the compass to this length and mark it off on the circle 31 times (Fig. 80*b*).

In marking round parts prior to their machining first determine their centre, as, for example, in the flange with six equi-spaced holes shown in Fig. 81*d*. Before marking a ring-shaped flange (Fig. 82*a*) a wooden plug should be tightly driven into it for marking the centre of the ring. It is a simple matter to find this centre with the aid of a specially designed device called the centre-finder (see Fig. 82*b*). Pressing the angular crosspiece of the device against the ring, draw a line along the blade. Shift the centre-finder to another position and draw another line. The point of intersection of these lines will be the required centre. The further marking is shown in Fig. 81*b*. It is accomplished by means of marking dividers fitted with sharp needles. The required six centres of the holes are punched as shown in Fig. 81*c*.

On learning the above rules and methods of dividing a circle into equal parts, the student must do a number of exercises in drawing the outlines of machine parts similar to those shown

Table 6

Number of parts *n*	Factor *k*	Number of parts *n*	Factor *k*	Number of parts *n*	Factor *k*	Number of parts *n*	Factor *k*	Number of parts *n*	Factor *k*
1	0.00000	21	0.14904	41	0.07655	61	0.05148	81	0.03878
2	1.00000	22	0.14231	42	0.07473	62	0.05065	82	0.03830
3	0.86603	23	0.13617	43	0.07300	63	0.04985	83	0.03784
4	0.70711	24	0.13053	44	0.07134	64	0.04907	84	0.03739
5	0.58779	25	0.12533	45	0.06976	65	0.04831	85	0.03693
6	0.50000	26	0.12054	46	0.06824	66	0.04758	86	0.03652
7	0.43388	27	0.11609	47	0.06679	67	0.04687	87	0.03610
8	0.38268	28	0.11196	48	0.06540	68	0.04618	88	0.03559
9	0.34202	29	0.10812	49	0.06407	69	0.04551	89	0.03529
10	0.30902	30	0.10453	50	0.06279	70	0.04486	90	0.03490
11	0.28173	31	0.10117	51	0.06156	71	0.04423	91	0.03452
12	0.25782	32	0.09802	52	0.06038	72	0.04362	92	0.03414
13	0.23932	33	0.09506	53	0.05924	73	0.04302	93	0.03377
14	0.22252	34	0.09227	54	0.05814	74	0.04244	94	0.03341
15	0.20791	35	0.08964	55	0.05709	75	0.04188	95	0.03306
16	0.19509	36	0.08716	56	0.05607	76	0.04132	96	0.03272
17	0.18375	37	0.08481	57	0.05509	77	0.04079	97	0.03238
18	0.17365	38	0.08258	58	0.05414	78	0.04027	98	0.03205
19	0.16459	39	0.08047	59	0.05322	79	0.03976	99	0.03173
20	0.15643	40	0.07846	60	0.05234	80	0.03926	100	0.03141

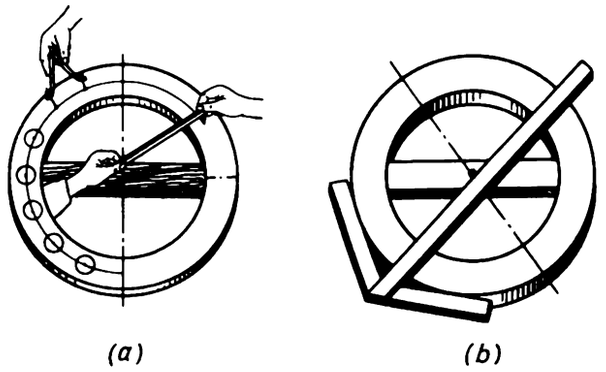


Fig. 82

in Figs. 70 through 79. In addition to the rules and methods the student must study the proper use of the instruments designed for drawing straight lines, circles and arcs.

Questions

1. Into how many equal parts is it possible to divide a circle with the aid of a 45°-45° triangle?
2. Into how many equal parts is it possible to divide a circle by means of a compass?
3. How is a circle divided into three equal parts?
4. How is the table of factors used?
5. What is the centre-finder used for?

Exercise 9

Divide a circle into 3, 6, 8 and 5 equal parts. Draw the outlines of a machine part similar to that in Fig. 70*f*.

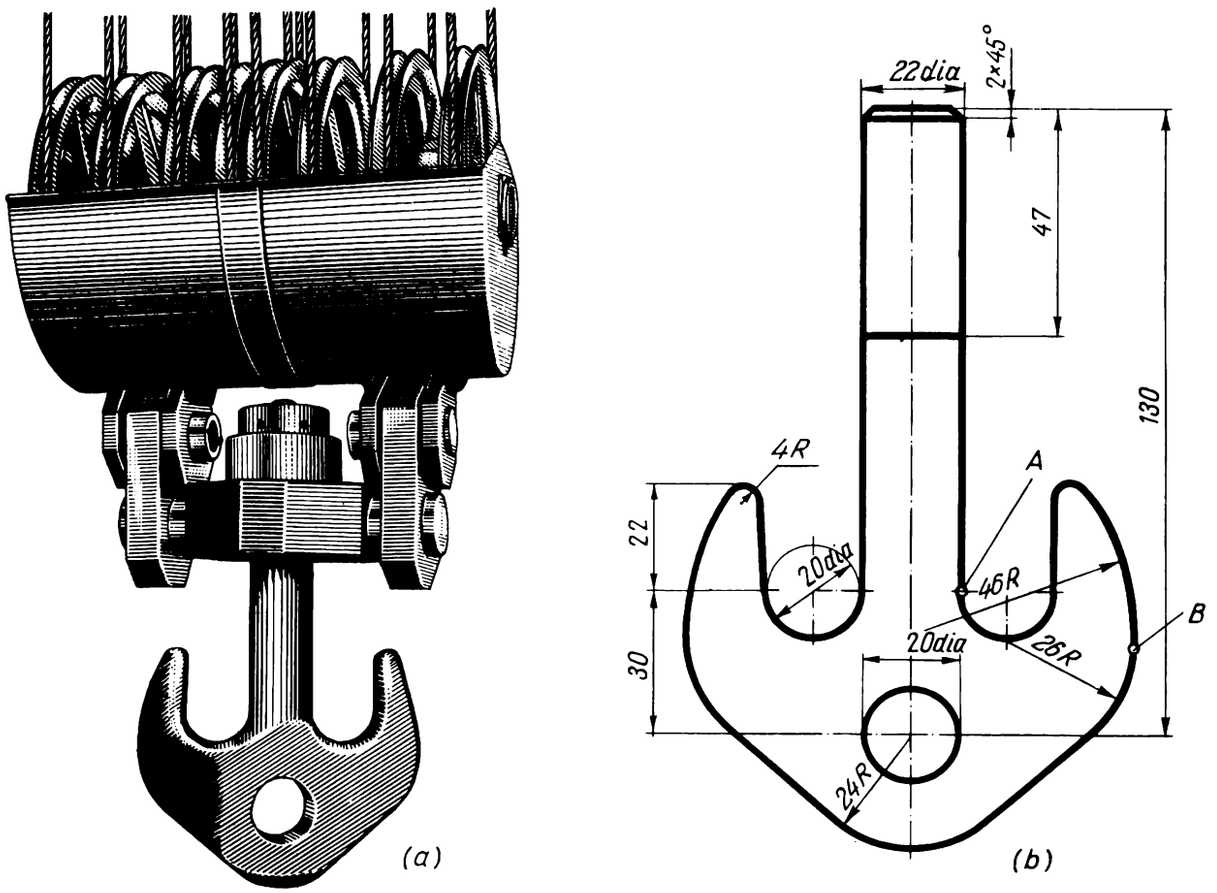


Fig. 83

CHAPTER 4

TANGENCY CONSTRUCTIONS

The outlines of many parts of machines, apparatus, instruments and devices consist of straight lines and arcs gradually merging into one another. Such gradual continuation of one line (whether straight or curved) into another (straight or curved) is termed *tangency* (or sometimes *conjunction*).

Figs. 83 and 84 illustrate some applications of tangent lines in engineering. On the drawing of a double hook (Fig. 83*b*) one can see a straight line tangent to an arc at *A*, an arc (46*R*) tangent to another arc (26*R*) and some other examples of tangency. Similar tangencies are seen in the drawing of a pump casing (Fig. 84*b*).

It is practically impossible for a draftsman to carry out tangency constructions of required accuracy without knowing the appropriate rules. The aim of this chapter is to teach these rules and their applications in engineering drawing.

1. DRAWING LINES TANGENT TO A CIRCLE

To draw lines tangent to a circle through a given point *A* located outside the circle. Connect the given point *A* (Fig. 85*a*) to the centre *O* of the circle with a straight line, *AO*. Divide this line into two equal parts and from its mid-point (O_1) with the radius O_1A describe an auxiliary circle which will intersect the given circle at two points: *D* and *E*. Join these points with the point *A* by lines *AD* and *AE* which will be tangent to the given circle at points *D* and *E*.

To draw a line tangent to two circles of different radii (*r* and *R*). Two cases are possible here: uncrossed tangents (Fig. 85*b*), and crossed tangents (Fig. 85*c*).

Uncrossed tangents are constructed in the following way. From *O* as a centre and with a radius equal to the difference of the radii of the given circles ($R-r$) draw an auxiliary circle. From the centre O_1 draw a line, O_1n, tangent to this circle at *n* as in the preceding case.

From the centre *O* draw a radius, *On*, and extend it to intersect the circle *R* at *m*. Draw the radius O_1K of the second circle parallel to the line *Om*. Join the points *K* and *m* with a straight line which will be tangent to the given circles.

Crossed tangents are constructed in a similar way, except that the auxiliary circle is described with a radius $R+r$. On drawing from O_1 a line tangent to the auxiliary circle at *m*, this point

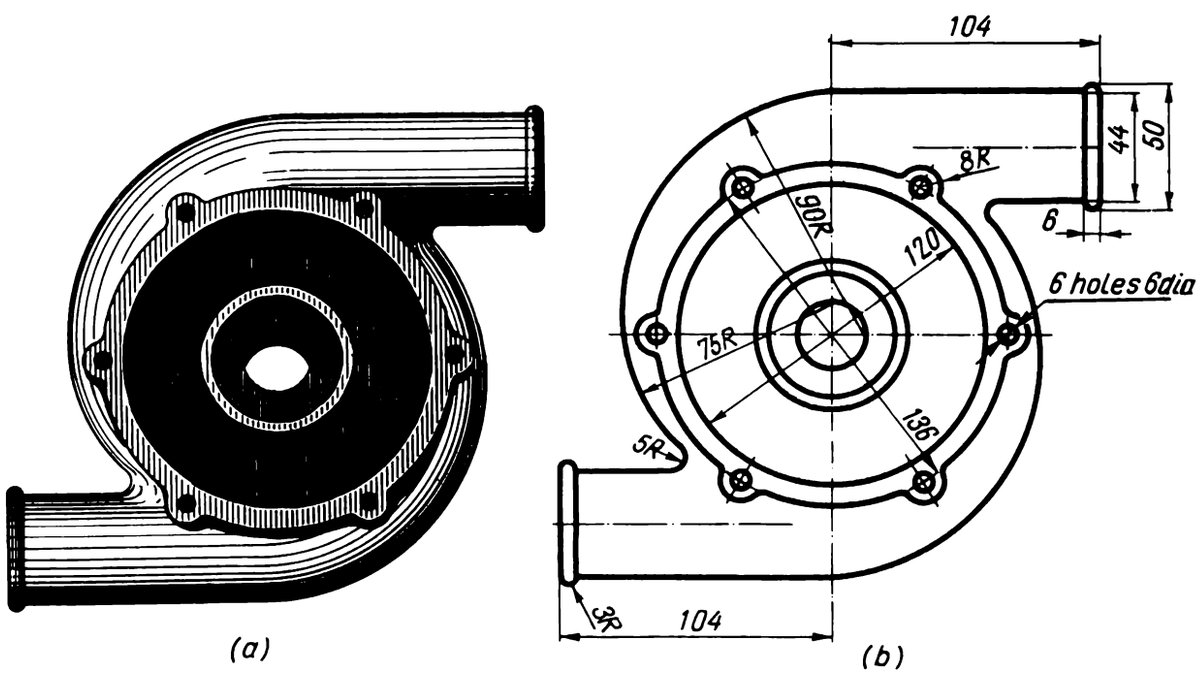


Fig. 84

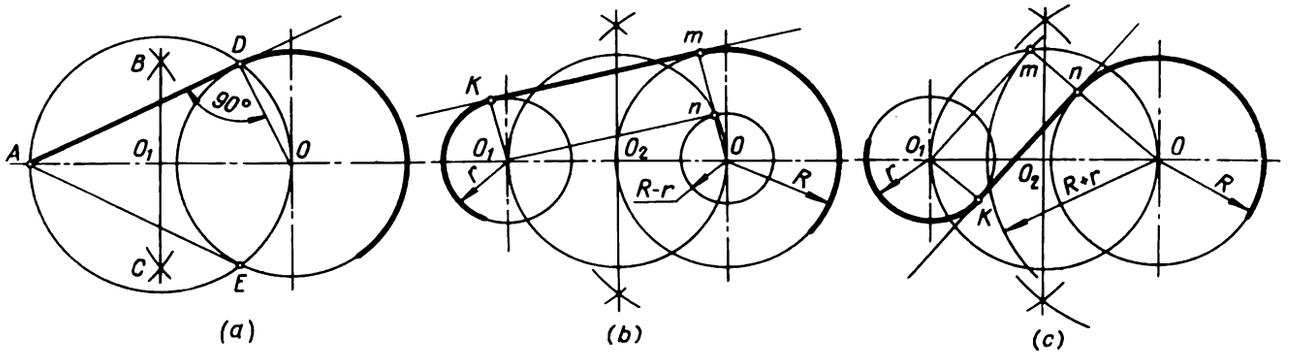


Fig. 85

is joined with O by radius Om, which intersects the circle R at n. The required tangent will be a line drawn through n, parallel to O_1m.

2. CONJUNCTIONS OF LINES

Line conjunctions may be conventionally divided into *immediate conjunctions* where one line, say, an arc, gradually merges into another, say, a straight line, without any intermediate lines, and *intermediate conjunctions*, i.e., conjunctions through intermediate arcs R which are usually called *conjunction arcs*, R in this case being termed the *conjunction radius.*

Immediate Conjunctions

1. Gradual continuation of a straight line Am into an arc of radius R (see Fig. 86*a*) at m, called the *point of conjunction*, can be obtained only when Om is perpendicular to Am. Proceeding from this rule we find the point of conjunction, which will be the point of demarcation between the straight line and the arc. This will help in inking the drawing or while making heavy lines with a pencil.

2. Gradual continuation of an arc of radius R into another arc of radius R_1 (see Fig. 87*a*) can be obtained only if the point of conjunction n is located on the straight line OO_1 drawn through the centres of the given arcs.

Shown in Figs. 86*b* and 87*b* are a shackle and a pawl, respectively. To draw the outlines of these parts (Figs. 86*c* and 87*c*) with all required conjunctions, it is necessary to find the corresponding points of conjunction. In Fig. 86*c*, for example, the straight line m_1m merges into the arc 52R at conjunction point m which is found by drawing the perpendicular Om to the straight line m_1m. In Fig. 87*c* the point of conjunction n of two arcs is found by joining O and O_1 (the centres of the arcs $R=49$ mm and $R=100$ mm) by a straight line. The second point of conjunction n_1 of two arcs ($R=172$ mm and $R=49$ mm) is determined in the same way.

Conjunctions Through Intermediate (Tangent) Arcs

To construct arcs tangent to the sides of angles. Straight lines may intersect at acute, right or obtuse angles. The construction of arcs tangent to the sides of various angles is also called rounding off angles.

Let us construct an arc of a given radius *(R)* tangent to the sides of a right (Fig. 88*a*), an acute (Fig. 89*a*), and an obtuse (Fig. 90*a*) angle. It is done according to the general rules of geometrical constructions.

Both sides of the angles under consideration will be tangent to the required arc. Hence, the centre of the arc must be at an equal distance (radius R) from the intersecting straight lines. Draw two lines parallel to and within the sides of the angle to intersect at O, the distance between the parallel lines and the respective sides being equal to the given radius R. The point of intersection O will be the centre of the required tangent arc.

From the point O draw perpendiculars On and On_1 to the sides of the angle to obtain the points of tangency n and n_1. With O as a centre and with a radius R draw the required arc to join the points n and n_1. Thus, the angles are

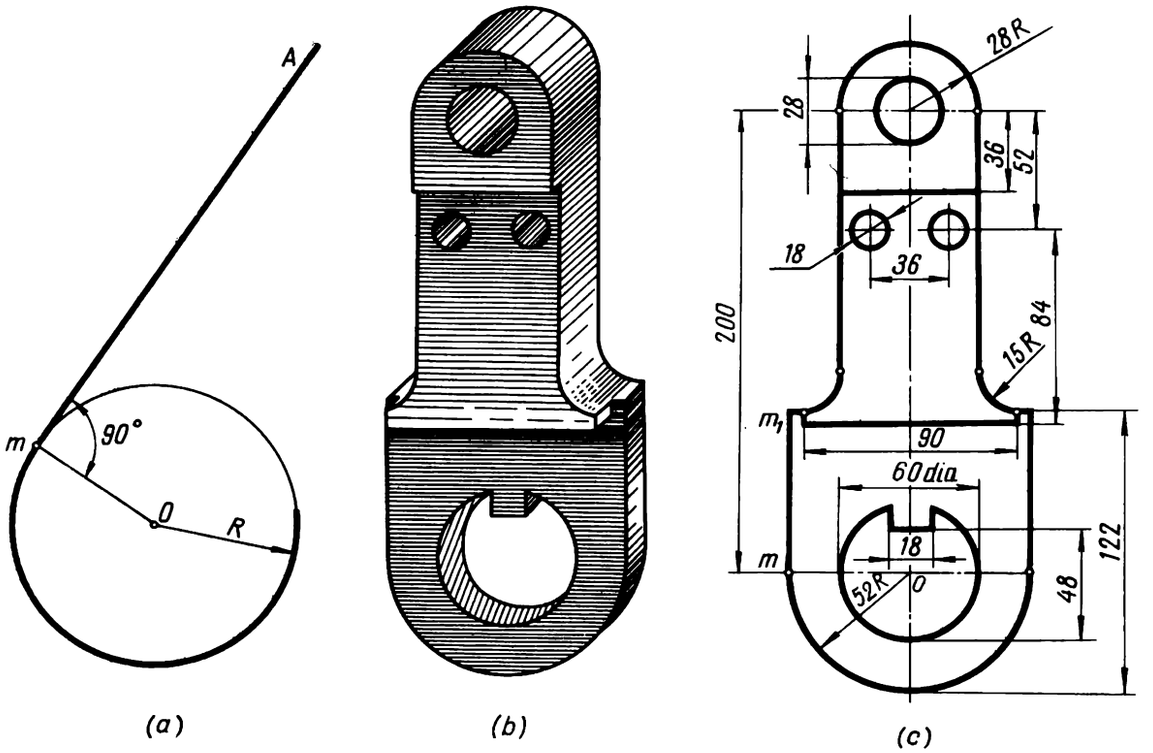

A
m
90°
O
R
28R
28
36
52
18
36
200
15R 84
m1
90
60 dia
18
m
52R
O
48
122
(a)
(b)
(c)

Fig. 86

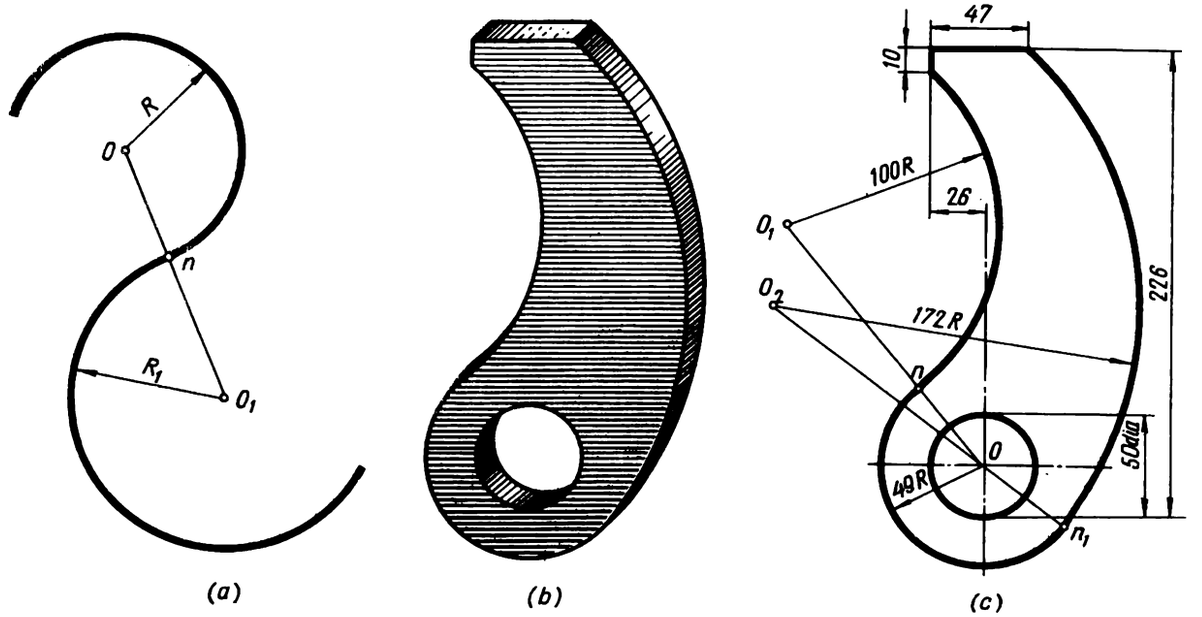

R
O
n
R1
O1
47
10
100R
26
O1
O2
172R
226
O
50 dia
49R
n1
(a)
(b)
(c)

Fig. 87

rounded off by an arc of a given radius. Shown in Figs. 88*b*, 89*b*, and 90*b* are various machine parts: a cover, a cramp and a clamp, respectively.

In drawing the visible outlines of these parts use the above method.

To draw an arc of radius *r* tangent to a straight line and another arc (Fig. 91*a*) of radius *R* with point *O* as a centre (the relative positions of the arc *R* and the line *AB* are given by the angle of the straight line with the vertical, and the distance between a point on the line and the centre *O*), first draw the arc *R* and the straight line.

Draw a line, *ab*, parallel to the given line *AB* at a distance *r* from it. From point *O* draw an arc of radius $R+r$ to intersect the line *ab* at point O_1, which will be the centre of the required

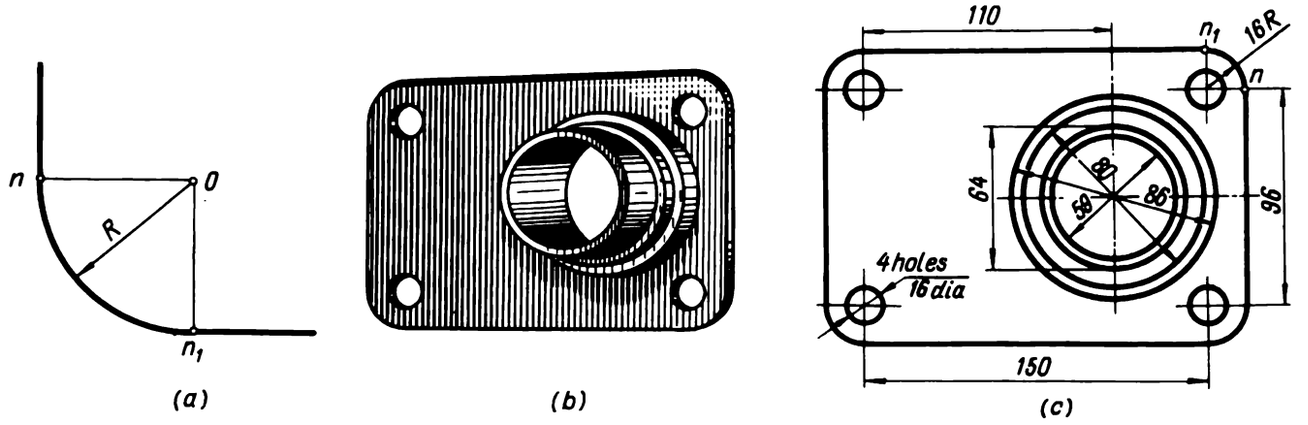


Fig. 88

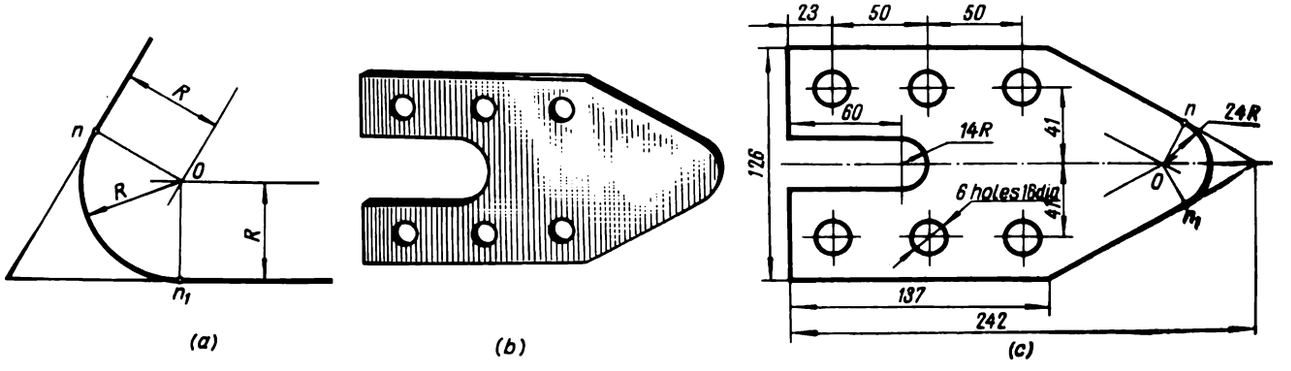


Fig. 89

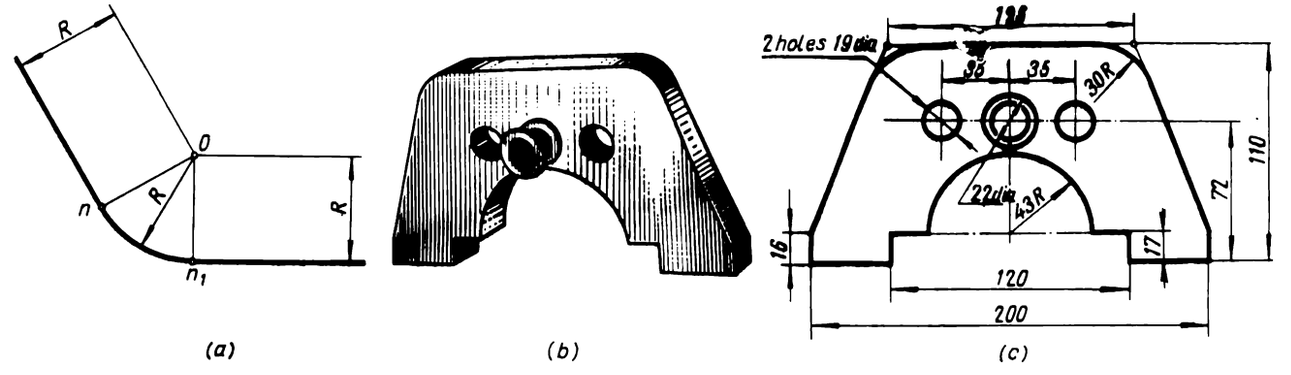


Fig. 90

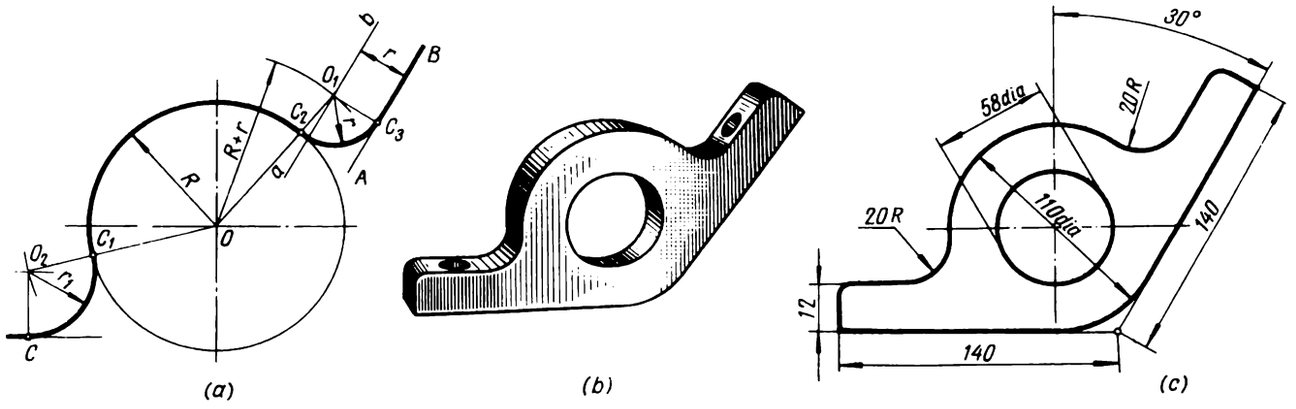


Fig. 91

arc r. The point of tangency C_2 is located by joining the points O and O_1. The point of tangency C_3 is located by dropping a perpendicular, O_1C_3, from the centre O_1 to the line AB.

Fig. 91*b* shows a bracket whose drawing (Fig. 91*c*) is made in accordance with the above method.

Fig. 92*a* demonstrates the conjunction of a straight line, drawn through the centre O of an arc of radius R, with this arc through a tangent arc of radius r.

The centre O_1 of the required arc r is found as the point of intersection of an auxiliary straight line drawn parallel to the given line at a distance r from it and an arc of radius $R-r$ with O as a centre. The point of tangency C_1 is located by dropping a perpendicular from O_1 to the given line. The point of tangency C is the point of intersection of the extended line OO_1 and the arc R. Such a conjunction is to be constructed, for example, in drawing the visible outlines of the flywheel shown in Fig. 92*b*.

Its drawing (Fig. 92*c*) incorporates a number of conjunctions of a straight line with an arc where spokes contact the rim. The position of the straight line with respect to the centre O of the arc ($R=64/2=32$ mm) is specified by a distance of $12/2=6$ mm. The radius of the tangent arc $r=4$ mm.

To draw an arc tangent to two other arcs. There are three possible variants:

1. *External tangency* — the centres of adjoining arcs are located on the opposite sides of the point of tangency, as in Fig. 93*a*.

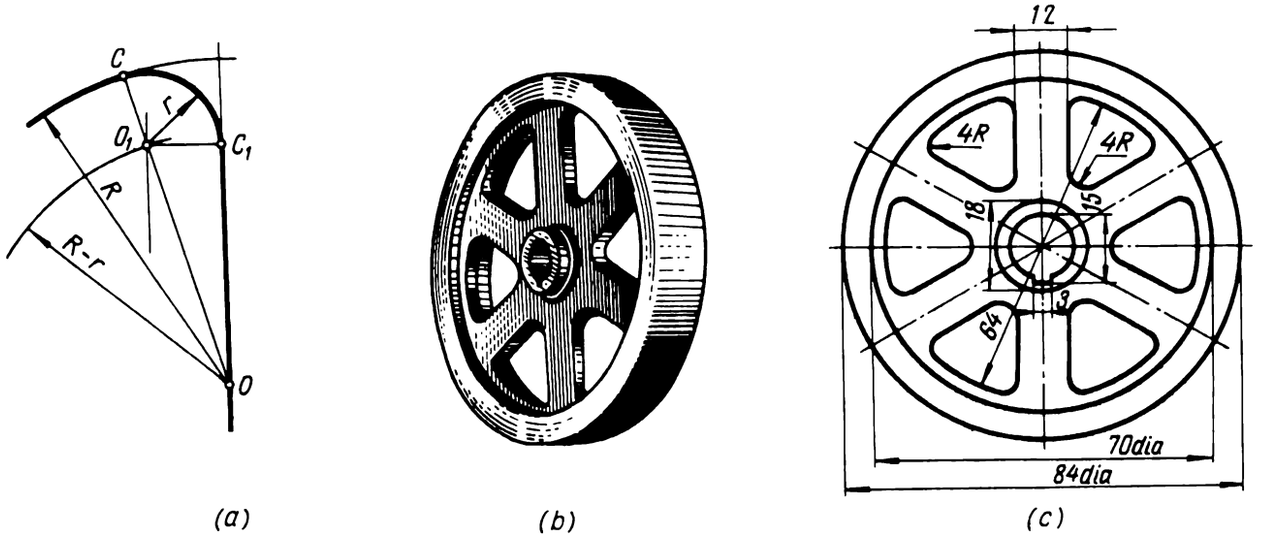


Fig. 92

2. *Internal tangency* — the centres of adjoining arcs are located on the same side of the point of tangency, as in Fig. 93*b*.

3. Combination of (1) and (2), see Fig. 94*a*.

Construction of external tangency.

Given:

1. Two arcs with radii R_1 and R_2 (Fig. 93*a*).
2. Distances l_1 and l_2 between the centres of these arcs.
3. Radius R of the tangent arc.

Required:

1. To determine the position of the centre O_2 of the tangent arc.
2. To find the points of tangency S and S_1.
3. To draw the tangent arc.

Sequence of construction. Mark off the given distances l_1 and l_2 between O and O_1 and from these points as centres draw the circles R_1 and R_2. Then from O and O_1 describe arcs with radii R_1+R and R_2+R, respectively. The intersection of these arcs will be the centre of the required tangent arc.

To find the points of tangency draw the lines OO_2 and O_1O_2 which will intersect the given circles at S and S_1, respectively.

From O_2 as a centre and with radius R draw an arc between the points of tangency S_1 and S.

A practical application is shown in Fig. 93*c* and *d*. The right-hand side of the cover is an example of external tangency. Given are the radii of the two arcs: $R_1=22$ mm and $R_2=11$ mm; the distances $l_1=0$ and $l_2=42$ mm; and the radius of the tangent arc $R=20$ mm.

Construction of internal tangency.

Given:

1. Two arcs with radii R_1 and R_2 (Fig. 93*b*).
2. Distances l_1 and l_2 between the centres of these arcs.
3. Radius R of the tangent arc.

Required:

1. To determine the position of the centre O_2 of the tangent arc.
2. To find the tangent points S and S_1.
3. To draw the tangent arc.

Sequence of construction. Mark off the given distances l_1 and l_2 between O and O_1 and from these points as centres draw the given circles. In this case the radius of the tangent circle must be greater than that of either circle. From O and O_1 as centres draw two arcs with radii $R-R_1$ and $R-R_2$, respectively. The intersection of these arcs is the required centre O_2.

To find the points of tangency draw the lines OO_2 and O_1O_2 whose extensions will intersect the given circles at S_1 and S which are the required points.

From O_2 as a centre and with radius R draw the tangent arc SS_1.

A practical application is shown on the left-hand side of Fig. 93*c*. The radii of the given arcs are: $R_1=22$ mm and $R_2=11$ mm; the radius of the tangent arc $R=50$ mm, the centre distances being $l_1=0$ and $l_2=42$ mm.

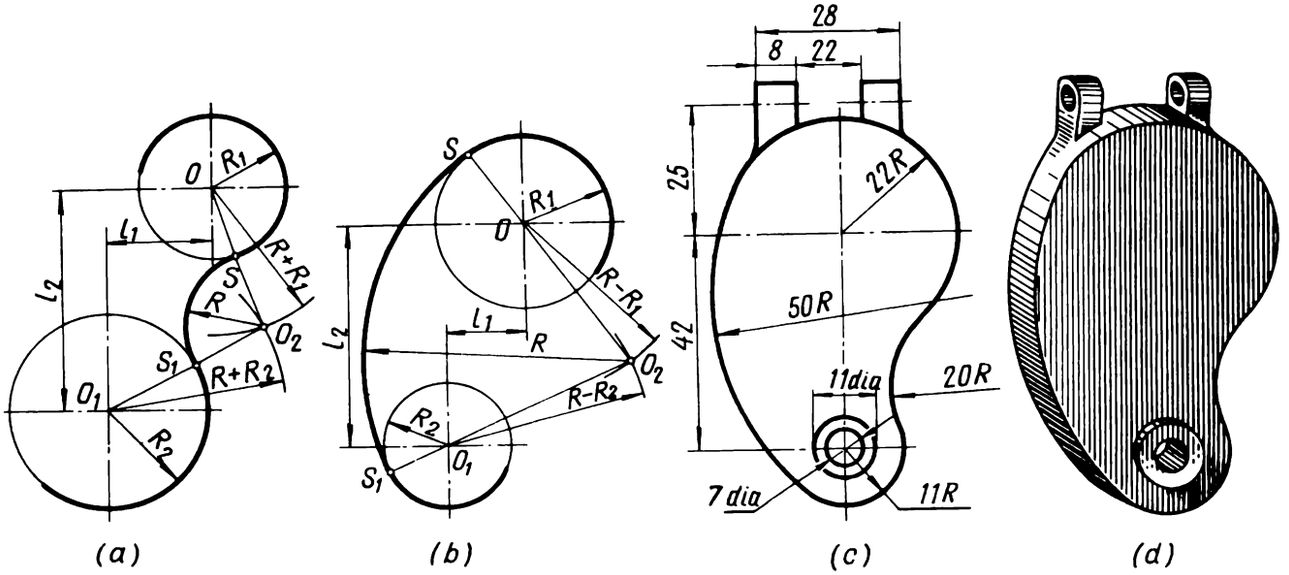


Fig. 93

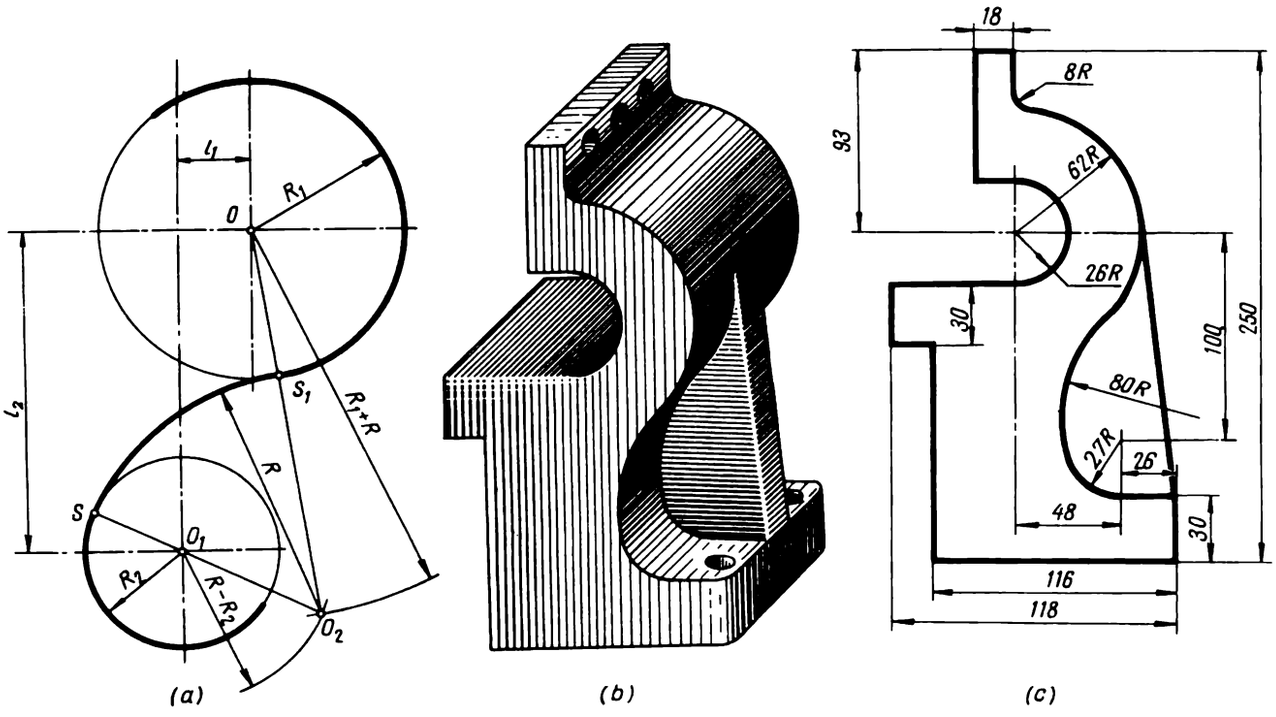


Fig. 94

Construction of combined tangency.

Given:

1. Two arcs with radii R_1 and R_2 (Fig. 94*a*).
2. Distances l_1 and l_2 between the centres of these arcs.
3. Radius R of the tangent arc.

Required:

1. To determine the position of the centre O_2 of the tangent arc.
2. To find the points of tangency S and S_1.
3. To draw the tangent arc.

Sequence of construction. Mark off the given distances l_1 and l_2 between O and O_1 and from these points as centres draw the given circles. Then draw two arcs of radii $R-R_2$ and R_1+R as illustrated. The intersection of these arcs locates the required centre, O_2, of the tangent arc.

To find the points of tangency draw the lines OO_2 and O_1O_2 which will intersect the given arcs at the required points S_1 and S, respectively.

From O_2 as a centre and with radius R draw the tangent arc SS_1.

Fig. 94*b* and *c* illustrates the practical application of combined tangency. The radii of the given arcs are: $R_1=62$ mm and $R_2=27$ mm, the radius of the tangent arc being $R=80$ mm. The centre distances: $l_1=48$ mm and $l_2=100$ mm.

In drawing the outlines of machine parts having many conjunctions, it is important to ascertain how they should be constructed: as gradual continuations of lines or by means of tangent arcs.

The best way of acquiring practical skill in constructing tangencies is by exercising in drawing outlines of complicated parts. First it is recommended to read through the assignment, to plan the sequence of tangency constructions and then to perform the necessary constructions.

Fig. 95 shows the construction of a lifting hook whose outlines have many different tangent lines.

Constructing the Outlines of a Hook

Through the centre O (Fig. 95*c*) draw the axes, then from this centre and with a radius equal to $\frac{a}{2}$ describe a circle (a and other dimensions are to be taken from the table of the USSR Standard).

Mark off the lengths l, l_1 and l_2 on the vertical axis; then mark off on both sides of point *4* the dimensions $\frac{d_1}{2}$ and $\frac{d}{2}$, and through their ends

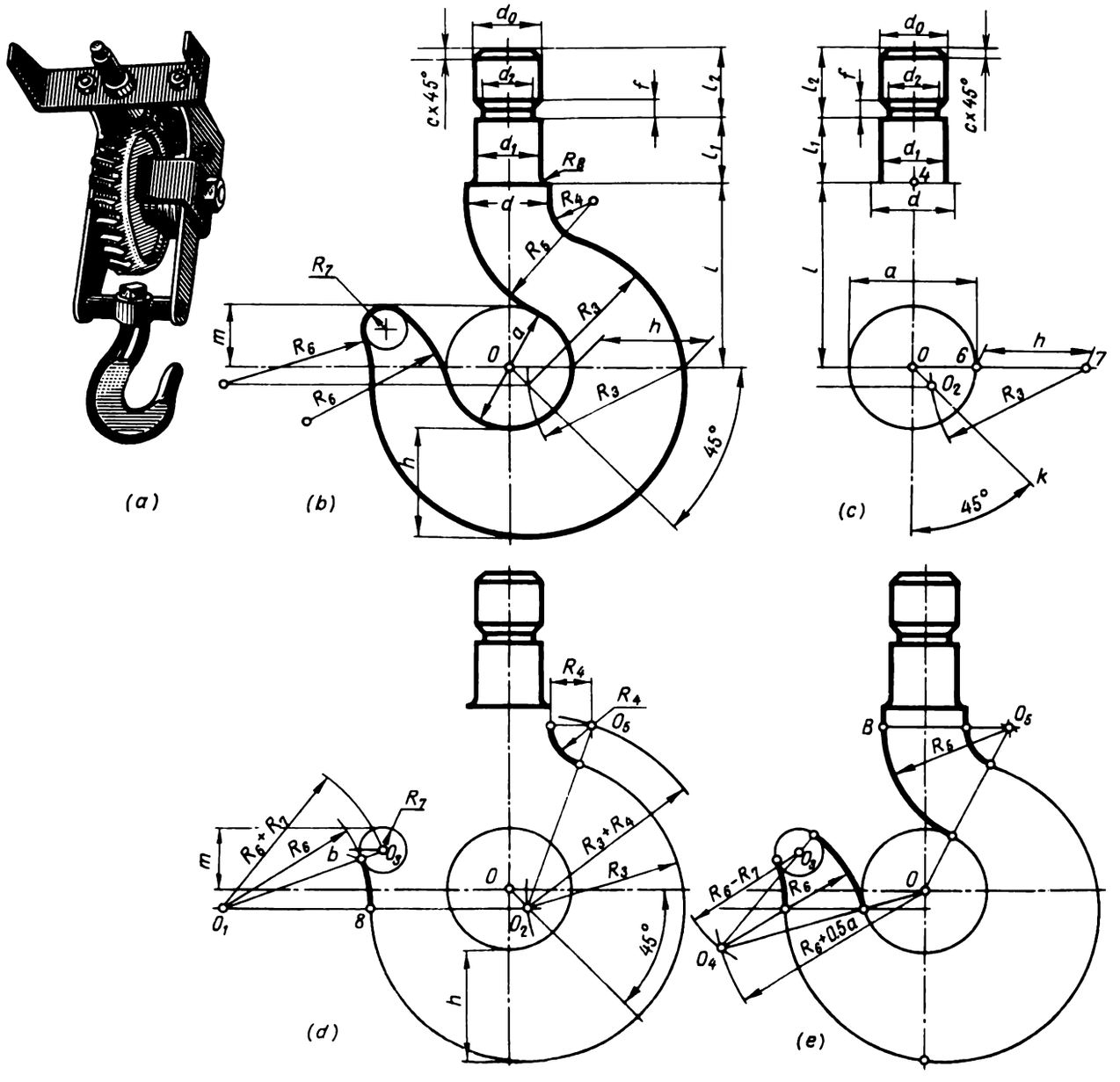


Fig. 95

draw straight lines parallel to the vertical axis. By marking off the dimension h on the horizontal axis (from point *6* to the right) we obtain point *7*. Draw a straight line, OK, through O at an angle of 45° to the vertical axis. From point *7* as a centre and with radius R_3 describe an arc to intersect OK at O_2. Through the latter point draw a horizontal line. From O_2 as a centre and with radius R_3 describe an arc (Fig. 95*d*) which intersects the horizontal line at point *8*. To the left of this point mark off the dimensions R_6 on the horizontal line to obtain O_1. From this point as a centre and with radius R_6 desribe an arc.

Draw a straight line parallel to the horizontal axis at distance m above it. Likewise draw another straight line, bO_3, at distance R_7 below the first line.

From O_1 as a centre and with a radius $R_6 + R_7$ draw an arc to intersect bO_3 at O_3, the latter point being the centre of the tangent arc.

All the preparatory constructions accomplished, draw the following conjunctions:

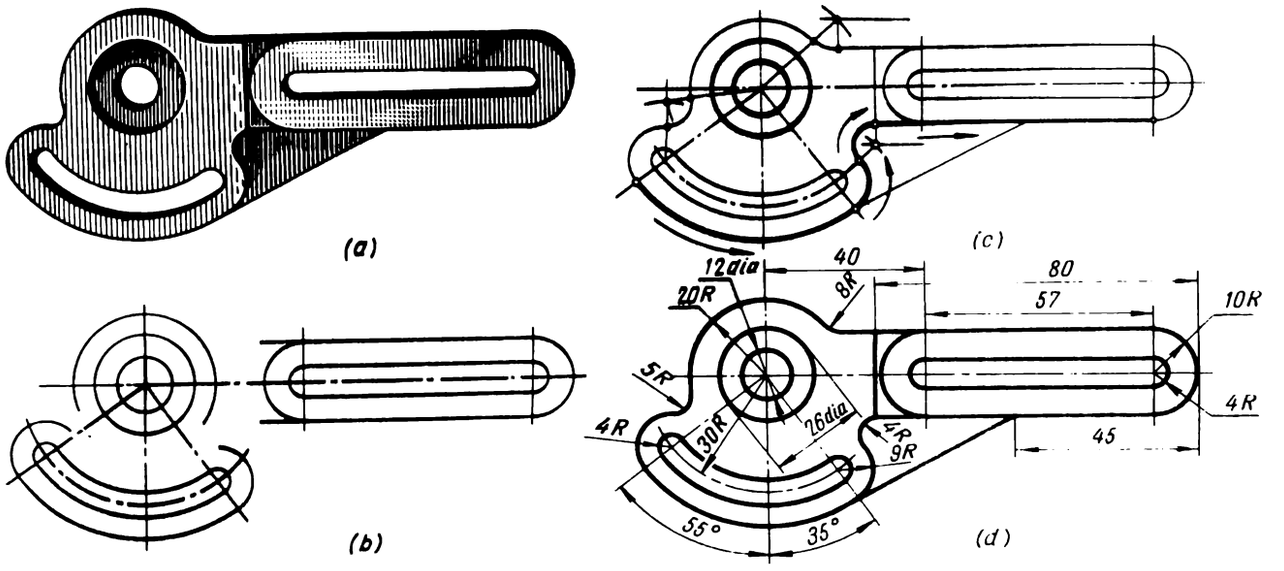


Fig. 96

I. ***Conjunction of the arc*** R_7 ***with*** O_3 ***as a centre and the arc of radius*** $\frac{a}{2}$ ***with*** O ***as a centre*** (Fig. 95*b*). Swing two arcs $R_6 - R_7$ and $R_6 + \frac{a}{2}$, as illustrated in Fig. 95*e*. The intersection of these arcs is the required centre, O_4, of the tangent arc. The points of tangency are found in the usual way, i.e., by drawing the lines OO_4 and O_3O_4.

II. *Conjunction of three arcs* (Fig. 95*d*): R_3 with O_2 as a centre, R_7 with O_3 as a centre, and R_6 (the tangent arc) with O_1 as a centre.

III. *Conjunction of the arc of radius* $\frac{a}{2}$ with O as a centre and the *vertical line* drawn through the point B through the tangent arc R_5 with O_5 as a centre (Fig. 95*e*). The points of tangency are located: one at the point of intersection of the vertical line and the perpendicular dropped to it from O_5, the other at the point of intersection of the arc of radius $\frac{a}{2}$ and the line OO_5.

Another practical application of tangency constructions is shown in Fig. 96.

3. COMPOUND CURVES

The outlines of certain machine parts, instruments, apparatus and tools incorporate convex curves consisting of a number of arcs tangent to each other. An open convex curve is called a compound curve, a closed one an oval. Some ovals have two axes of symmetry and some only one (the so-called egg-shaped oval).

The *oval* (Fig. 97*a*) consists of four arcs (two of radius r and two of radius R) tangent to each other.

This is a case of internal tangency, since the centres O_1 and O_2 of the arcs r are located within the tangent arc R (or in other words, all the centres O_1, O_2, and E are on one side of the tangent arc).

Oval-shaped outlines are incorporated in the drawings of certain machine parts and tools, such as rotary files (Fig. 97*b*), lids (Fig. 97*c*), and so on.

It is frequent practice to draw the outlines of oval-shaped parts as well as to sketch them with the major and minor axes of the oval being given instead of the two radii.

To construct an oval with the major and minor axes given (Fig. 97*a*). Draw the axes and lay off their lengths: the major axis in the horizontal direction and the minor axis in the vertical one. Join the end points A and C of the axes with a straight line. From O as a centre and with a radius equal to the semi-major axis describe an arc to intersect the extension of the minor axis at N ($AO = NO$); from C as a centre and with a radius equal to CN draw an arc to intersect the straight line AC at point M ($CN = CM$). Then erect a perpendicular bisecting the line AM and

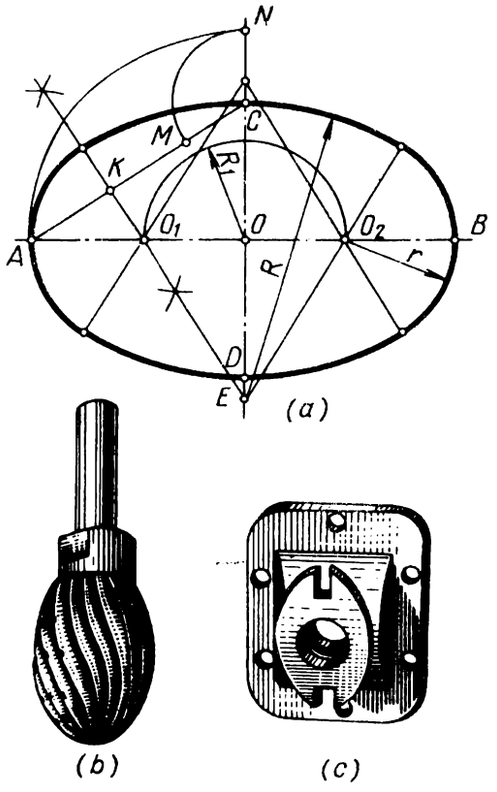


Fig. 97

extend it to intersect the major axis at point O_1 and the minor axis at point E. The point O_1 is the centre of the arc of radius $r=O_1A$, while E is the centre of the tangent arc of radius $R=EC$. The right-hand half of the oval is constructed in the same way.

The *egg-shaped oval* (Fig. 98*a*) differs from the regular oval in that it has only *one axis of symmetry*. The radius r_1 is not equal to r. The method of constructing the egg-shaped oval is similar to that used for the regular oval.

To construct an egg-shaped oval with the radius r_1 of the larger arc given (Fig. 98*a*).

With the radius r_1 and from the point O as a centre describe a circle. Join the point O_1 of intersection of this circle and the axis of symmetry to the end of the vertical diameter (point A) with a straight line. From A as a centre and with a radius equal to $2r_1$ describe the tangent

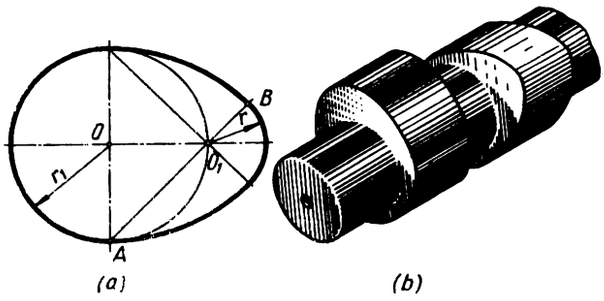


Fig. 98

arc to intersect the extension of the line AO_1 at point B. From O_1 as a centre and with radius $r=O_1B$ draw the smaller arc to complete the required oval.

A practical application is shown in Fig. 98*b* illustrating a portion of a camshaft.

Questions

1. Give the definition of tangency.
2. Characterize the external, internal and combined tangencies of arcs.
3. How are points of tangency determined?
4. In what sequence is the centre of a tangent arc determined?
5. How is a straight line drawn tangent to two given circles?
6. What is the difference between the regular and the egg-shaped oval?
7. How is an egg-shaped oval constructed if the radius of the larger tangent arc is given?

Exercise 10

1. Draw various kinds of conjunctions as in Figs. 86*a*, 88*a*, 89*a*, 92*a*, and 93*a*.
2. Draw the outlines of the machine parts shown in Figs. 87*b* and 91*b*.

Exercise 11

Construct an oval given the lengths of its axes: the major axis 90 mm and the minor axis 60 mm.

CHAPTER 5

NON-CIRCULAR CURVES

Non-circular curves — the ellipse, parabola, hyperbola, sinusoid, spiral of Archimedes, involute, cycloid, etc. — are frequently used in engineering drawing. As distinct from circular curves, these curves, which may be closed or open, cannot be adequately constructed with a compass; they are generally obtained by making use of French curves.

1. CONSTRUCTION OF CONIC SECTIONS

The ellipse, parabola, and hyperbola are usually called conic sections since they may be cut from a right circular cone.

The *ellipse* is a section cut from a right circular cone by a plane *P* (Fig. 99*a*) making an acute angle with the axis and cutting all the elements.

The *parabola* is a section cut from a cone by a plane *P* (Fig. 101*a*) parallel to one of the elements, say, *SC*.

The *hyperbola* is a section cut by a plane *P* making a smaller angle with the axis than the elements do (Fig. 104*a*). The section is usually taken parallel to the axis, which gives an equilateral hyperbola (see Fig. 104*b*).

The Ellipse. The ellipse is a plane curve generated by a point moving so that the sum of its distances from two given points, called the foci (F_1 and F_2 in Fig. 99*b*), is a constant equal to the long diameter, or major axis *(AB)*.

To construct an ellipse with its major axis AB and minor axis CD given.

Draw the given axes which should be perpendicular to and bisect each other at point *O* which is called the centre of the ellipse. Draw two concentric circles whose diameters are equal respectively to the major and minor axes of the ellipse. Divide each circle into 12 equal parts by drawing 30° and 60° radial lines, as shown in Fig. 99*b*. From the points where the radial lines cross the large circle, draw lines vertically inward, and, from the points where the same radial lines cut the small circle, draw lines horizontally outward until they intersect the previously drawn vertical lines. The intersections thus obtained determine points of the ellipse. Draw a smooth curve through these points using a French curve (see Fig. 99*c*).

Fig. 100*a* illustrates a practical application. Shown in this figure is a cylindrical metal container whose bottom is a semi-ellipse and is constructed according to the above method (see Fig. 100*b*). The major axis is equal to the diameter *D* of the container, its semi-minor axis

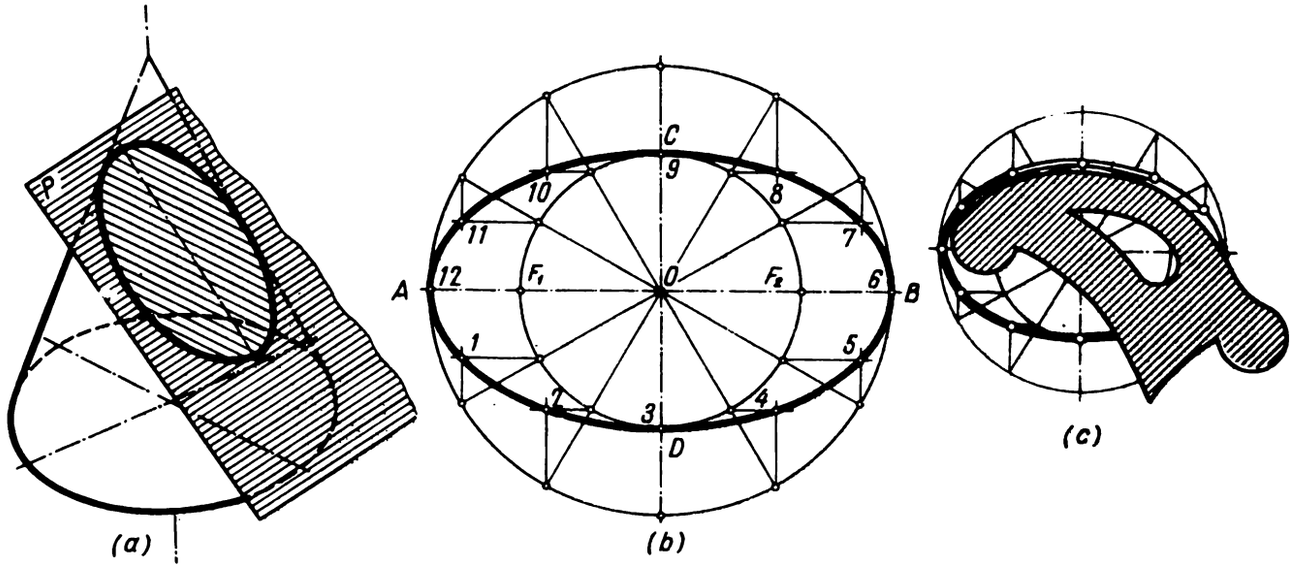


Fig. 99

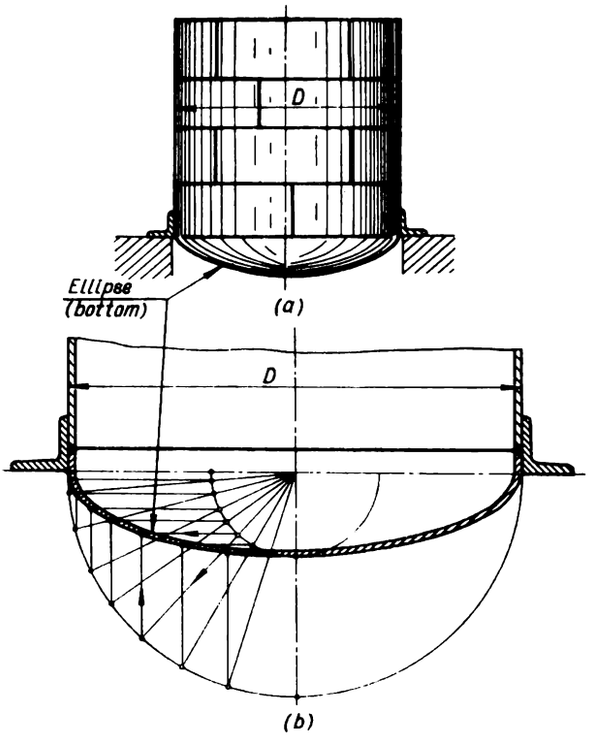


Fig. 100

being equal to the maximum distance between the major axis and the lowest point of the bottom, measured along the vertical axis.

The Parabola. The parabola is a plane open curve generated by a point moving so that its distance from a fixed point F, called the focus, is always equal to its distance from a straight line called the directrix (the line DD_1), which is perpendicular to the axis of symmetry (Fig. 101*b*).

The distance KF between the directrix DD_1 and focus F is called the parameter of the parabola and is designated as p.

The point O, located on the axis of symmetry and called the vertex of the parabola, bisects the parameter.

We shall consider two methods of constructing a parabola.

1. *To construct a parabola given the parameter p in millimetres* (see Fig. 101*b*).

Draw the axis of symmetry (the horizontal dot-and-dash line) and lay off the length $p=KF$. Draw the directrix DD_1 through K and perpendicular to the axis of symmetry. Bisect the length KF with the point O, which will be the vertex of the curve, the point F being its focus. To the left from O mark off a series of arbitrary points *(I* to *VI)* on the axis of symmetry spaced at gradually increasing distances between them and erect perpendiculars at these points. With a radius equal to the distance between the perpendicular and directrix, and from F as a centre describe arcs to intersect the perpendicular at two points (on both sides of the axis). For instance, with the radius $R_1=KV$ and F as a centre describe arcs to intersect the perpendicular erected at V at points *5* and 5_1.

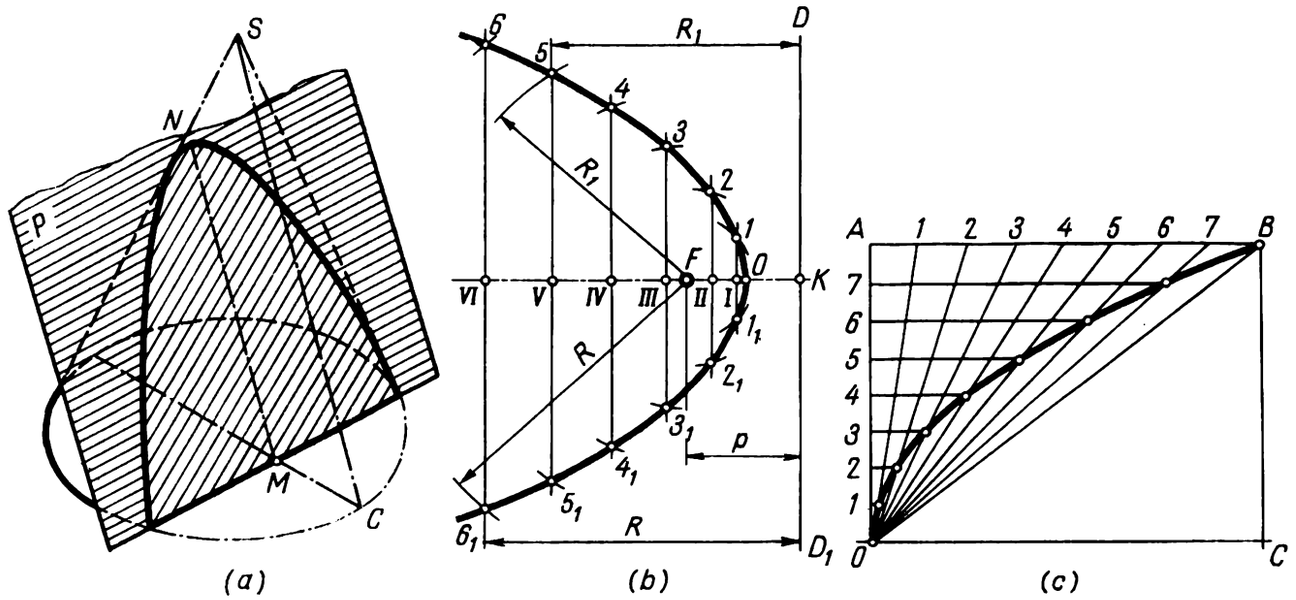


Fig. 101

The points thus obtained are on the required parabola. This is repeated and a number of symmetrical points are obtained to form a parabola which is then drawn with the aid of a French curve.

2. *To construct a parabola with point O as the vertex, axis OC and two symmetrically placed points B and B_1 given* (Fig. 101*c* shows only one branch of the required curve). Draw an auxiliary rectangle *ABCO*, divide its sides *AB* and *AO* into an equal number of parts, say, eight, and assign numbers to the points of division. Through the points on *AO*, draw lines parallel to the axis, and from *O* draw lines to the points on *AB*. The intersections of each two lines bearing the same numbers locate points on the parabola.

The parabola is frequently used in machine-tool building and other branches of mechanical engineering. The radial drilling machine shown in Fig. 102 is a typical application of the curve in question.

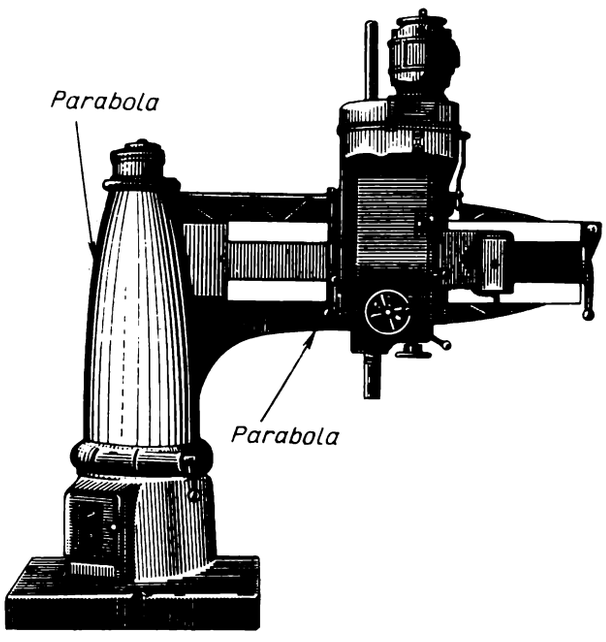


Fig. 102

Fig. 103*a* illustrates the construction of the arm parabola of the same machine. Given in this case are two points *(A* and *B)* of the required parabola and the straight lines *AC* and *BC* tangent to the parabola at the given points and intersecting at *C*. Each side of the angle *ACB* formed by the tangent lines is divided into ten equal parts.

Lines are drawn between points having the same number. Then the parabola is drawn with a French curve tangent to the intercepts of the intersecting lines.

The Hyperbola. The hyperbola is a plane open curve generated by a point moving so that the difference between its distances from two fixed points, *F* and F_1, called the foci, is a constant, which is equal to the distance between *A* and *B*, the vertices of the hyperbola (Fig. 104*d*).

The hyperbola has two branches and two axes of symmetry: the real axis (horizontal) and imaginary axis (vertical) intersecting at point *O*. In addition, it has two asymptotes which are intersecting straight lines passing through the centre *O* and tangent to the branches of the hyperbola at infinity.

Let us consider two methods of constructing a hyperbola.

1. *To draw a hyperbola with the distance FF_1 and vertices A and B given* (Fig. 104*d*). Draw the horizontal axis, and locate on it the foci *F* and F_1, and the vertices *A* and *B*, the point *O* bisecting the length FF_1. To the left from *F* mark off an arbitrary series of points (*1*, *2*, *3*, *4*, etc.) spacing them at gradually increasing distances. Then with radius *R* equal to the distance between the points *B* and, say, *3* and with *F* as a centre draw an arc. Next, with radius *r* equal to the distance between the points *A* and *3* and with F_1 as a centre draw an arc intersecting the first arc. The points of intersection of the arcs, *C* and C_1, are points on the required curve. Repeat this process for as many points on the axis as you choose. Draw a smooth curve through the plotted points.

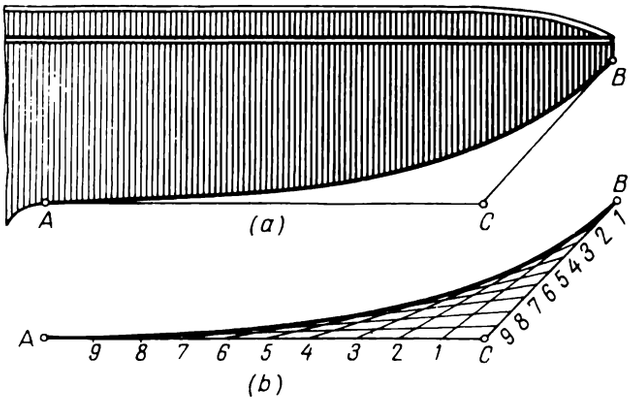


Fig. 103

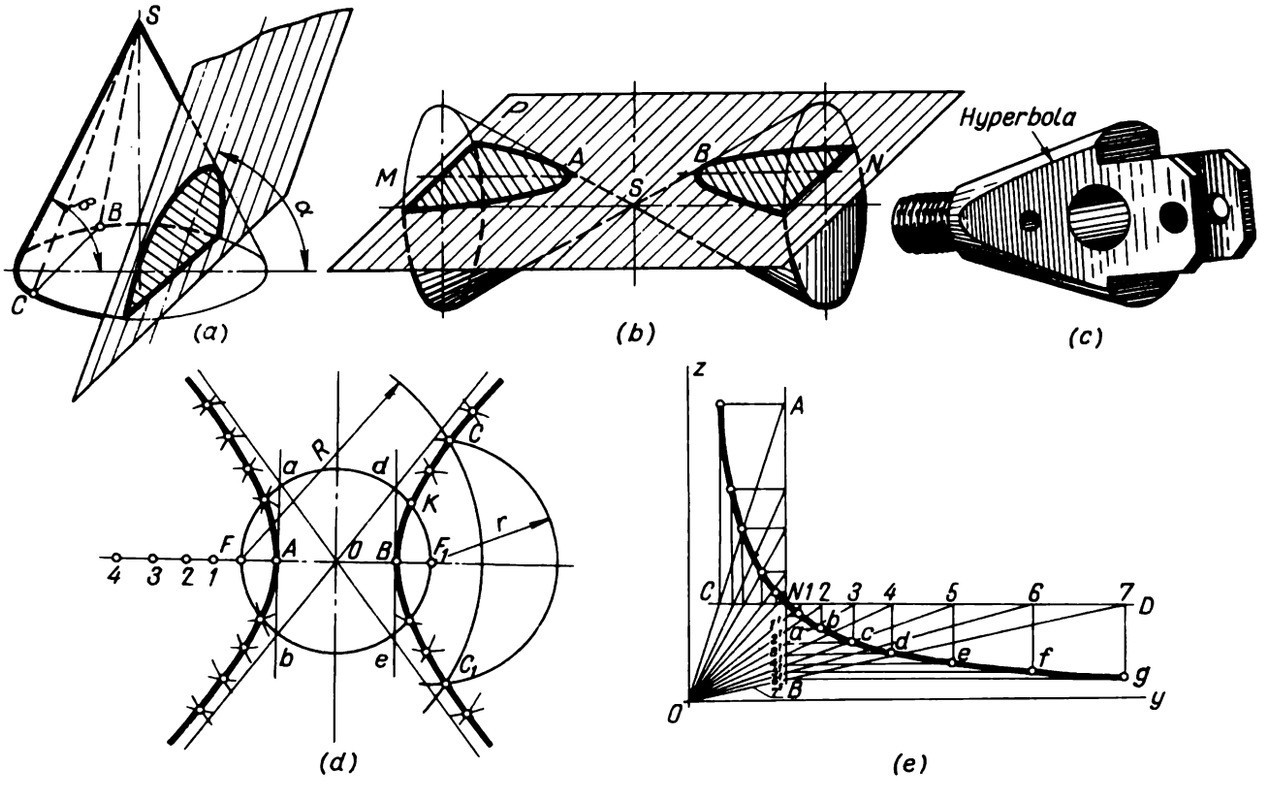


Fig. 104

Points on the left-hand branch of the curve are located in the same manner, the only difference being the changing of the foci.

Shown in Fig. 104*c* is a lug having a conic surface cut by two planes parallel to the axis of the cone. The sections cut from the cone are hyperbolas.

In engineering, use is commonly made of the rectangular or equilateral hyperbola, i.e., a hyperbola with the asymptotes at right angles to each other. This curve occurs, for instance, in thermodynamics in the study of the laws of expansion of gases. Fig. 104*e* illustrates the construction of an equilateral hyperbola.

2. *To construct an equilateral hyperbola with the asymptotes (axes oz and oy) and one point (N) on the curve given* (Fig. 104*e*). Through the given point *N* draw two lines *AB* and *CD* parallel to the axes *oz* and *oy*, respectively. Mark off a series of arbitrarily chosen points on the straight line *CD* (*1*, *2*, *3*, etc.) and through them draw lines parallel to the axis *oz*. From the origin *o* draw a series of radial lines through the same points to intersect the line *AB* at corresponding points *1'*, *2'*, *3'*, etc. The radial lines are drawn on both sides of the given point *N*. Lines drawn through *1* and *1'*, *2* and *2'*, *3* and *3'*, etc. parallel to the corresponding axes will intersect at points *a*, *b*, *c*, *d*, *e*, *f* on the required hyperbola.

2. THE SINUSOID

The sinusoid may be defined as a plane curve illustrating the law of variation of the sine, a trigonometrical function, with the central angle (from 0° to 360°).

D in Fig. 105*b* is called the amplitude of the sinusoid and *L* the wavelength or the cycle of the sinusoid. The wavelength of a normal sinusoid is equal to πD.

To draw a sinusoid given its wavelength *AB* and amplitude *D* (Fig. 105*a*). Draw a horizontal line *AB*, which will be the axis of the sinusoid, and mark off the given wavelength *AB* which is then divided into any number of equal parts, 12 for convenience. To the left describe a circle of a diameter equal to the given amplitude, with the point *A* lying on the circle as in Fig. 105*a*, and divide the circle also into 12 equal

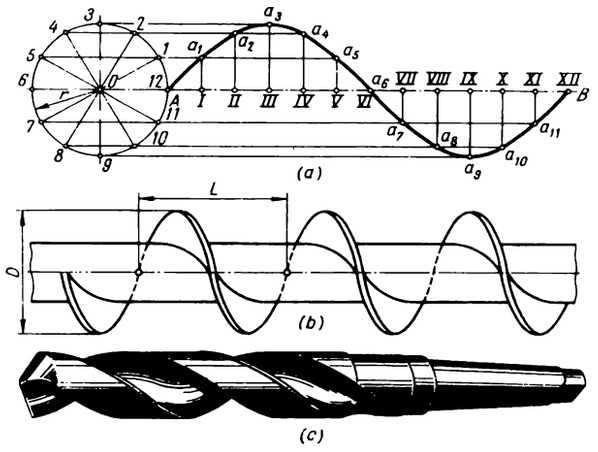


Fig. 105

parts, denoting them by arabic figures. Designate the points on the axis with Roman figures and erect a perpendicular to the axis at each one. Draw horizontal lines through the points dividing the circle *(1* through *11)* to intersect the corresponding perpendiculars at points a_1 through a_{11}. A smooth curve is then drawn through these points by means of a French curve to obtain the required sinusoid.

The sinusoid is frequently used in drawing screws, worms and drills (see Fig. 105*b* and *c*).

In making drawings of machine parts or tools incorporating a sinusoid, the wavelength L is usually chosen independently of the amplitude D. For example, in drawing the sinusoid of the worm shown in Fig. 105*b* the wavelength L is less than πD. Such a curve is called a "compressed" sinusoid. In drawing the sinusoid of the drill in Fig. 105*c* the wavelength is more than πD. In this case we have an "extended" sinusoid.

3. THE SPIRAL OF ARCHIMEDES

The spiral of Archimedes is a plane curve traced by a point which, starting from O, moves with uniform velocity along a ray, while the ray itself revolves with uniform angular velocity (Fig. 106).

To construct the spiral of Archimedes given its pitch (or lead) S, that is the distance between the centre O and point *VIII* (see Fig. 106*a*).

With O as a centre and a radius S draw a circle and divide it into any number of equal parts, say, eight. Divide the radius into the same number of equal parts and designate all division points by figures.

From O as a centre and with radii *O-1*, *O-2*, etc. describe arcs to intersect the corresponding radii at points *1* through *VIII*. Through the points thus obtained draw a smooth curve making use of a French curve.

The spiral of Archimedes is widely used in mechanical engineering. It is commonly resorted to in cam design. A typical example is shown in Fig. 106*b* presenting a chucking device for a lathe.. A schematic diagram of this device is given in Fig. 106*c*.

4. THE INVOLUTE

The involute is a spiral curve traced by a point on a taut cord unwinding from around a polygon or circle.

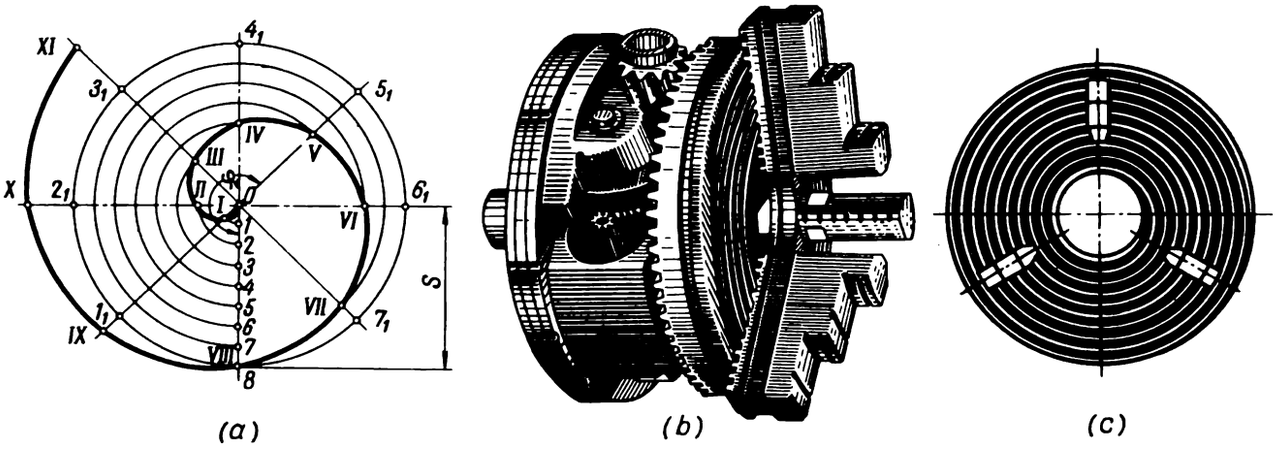
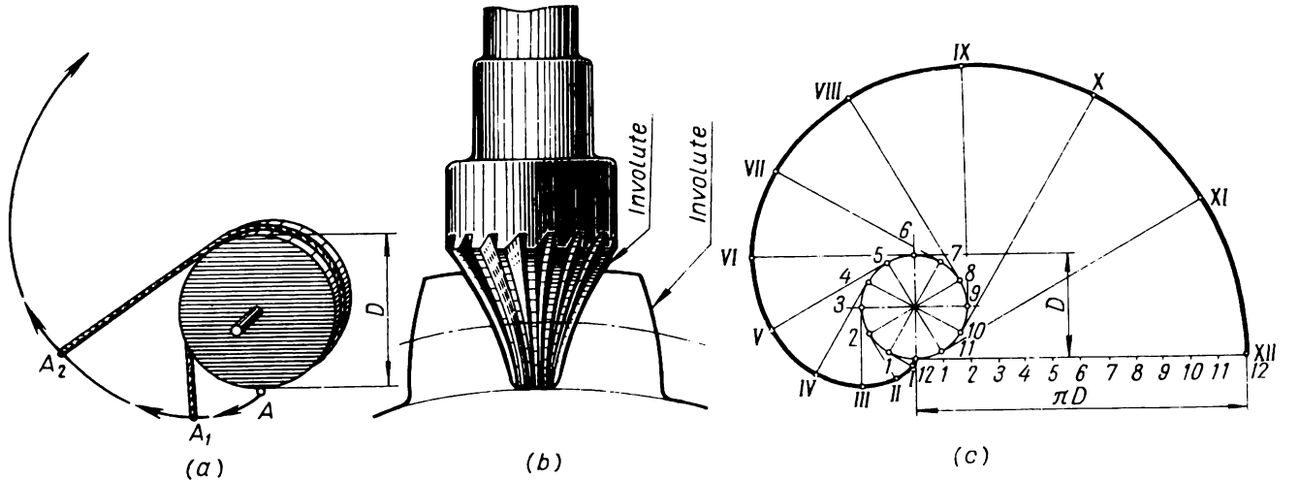


Fig. 106



(a) (b) (c)

Fig. 107

Generating the involute of a circle. Suppose a cord of length πD is wound on a fixed disk of diameter D (Fig. 107*a*). One end of the cord is fastened at A, then the other end, unwound from the disk in the direction indicated by the arrows, with the cord kept taut, will describe a plane curve. This curve will be the involute of a circle (see Fig. 107*c*).

The involute of a circle is the basis curve for gear teeth and gear-cutting tools (Fig. 107*b*).

To draw the involute of a circle. Divide a circle of given diameter D into any convenient number of equal parts (in Fig. 107*c* it is divided into 12 parts) and mark the points of division by figures *1* through *12*. Draw a tangent at point *12* and lay off on it the length of the circle which is equal to πD. Divide this length also into 12 equal parts. Draw tangents at points *1* through *11* and step off on them the following lengths of the corresponding arcs

$$1\ I=\frac{\pi D}{12};\quad 2\ II=\frac{2\pi D}{12}=\frac{\pi D}{6}$$

$$3\ III=\frac{3\pi D}{12}=\frac{\pi D}{4};\ \ldots;\ 12\ XII=\frac{12\pi D}{12}=\pi D$$

The points *I* through *XII* are then connected by a smooth curve.

5. CYCLOIDS

The cycloids form a group of curves generated by the path of a fixed point on the circumference of a rolling circle. When the circle rolls on a straight line AA_{12} (Fig. 108*a*), the path of the point A is called simply a *cycloid.* If a circle of diameter D rolls on the outside of another circle of radius R the path of the point A is called an *epicycloid* (Fig. 108*b*), whereas if a circle of diameter D rolls on the inside of another circle of radius R the path of the point A is called a *hypocycloid* (Fig. 108*c*).

To draw the cycloid (Fig. 108*a*), draw a horizontal line AA_{12} and mark off the length of the rolling circle (the circle of diameter D) equal to πD. Then divide the rolling circle and its length marked off on AA_{12} into, say, 12 equal parts. Erect perpendiculars at points *1′* through *12′* to intersect the extended horizontal axis of the rolling circle at points O_1 through O_{12}. Now draw horizontal lines passing through the points of division of the rolling circle. From O_1 through O_{12} as centres and with a radius equal to $\frac{D}{2}$ describe arcs to intersect the corresponding horizontal lines at the points A_1 to A_{12} of the required cycloid. A smooth curve is then drawn through these points with the aid of a French curve. The cycloid is used in the design of gear teeth and has some other applications. One of them is shown in Fig. 109 presenting a conveyor for mould boxes used in foundry shops.

To draw the epicycloid, see Fig. 108*b*. Describe a rolling circle of diameter D and a guiding circle of radius R tangent to it at point *12*. Divide the rolling circle into 12 equal parts. With O_0 as a centre and a radius equal to $R+\frac{D}{2}$ draw an auxiliary arc.

From the point A and clockwise lay out on

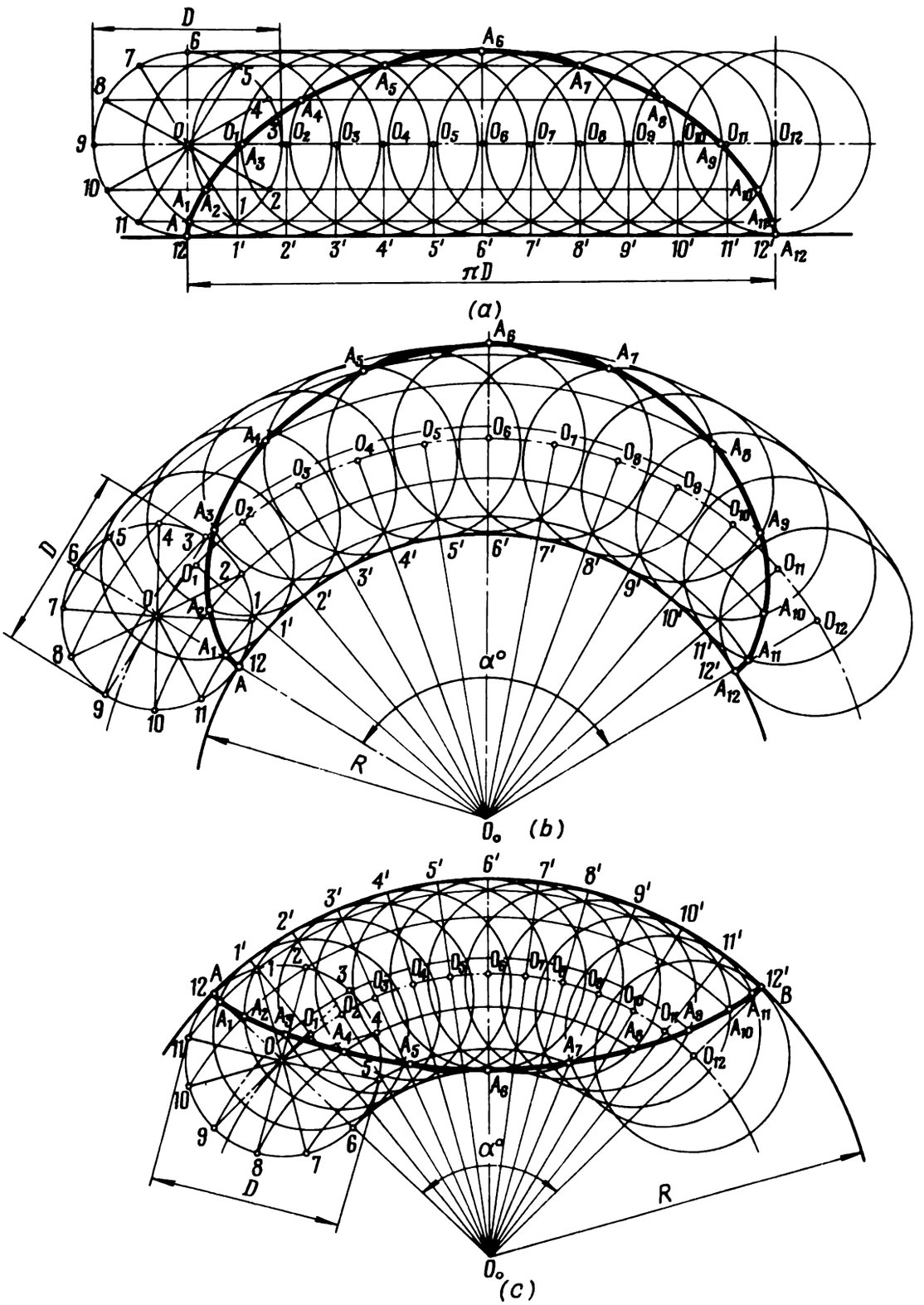


Fig. 108

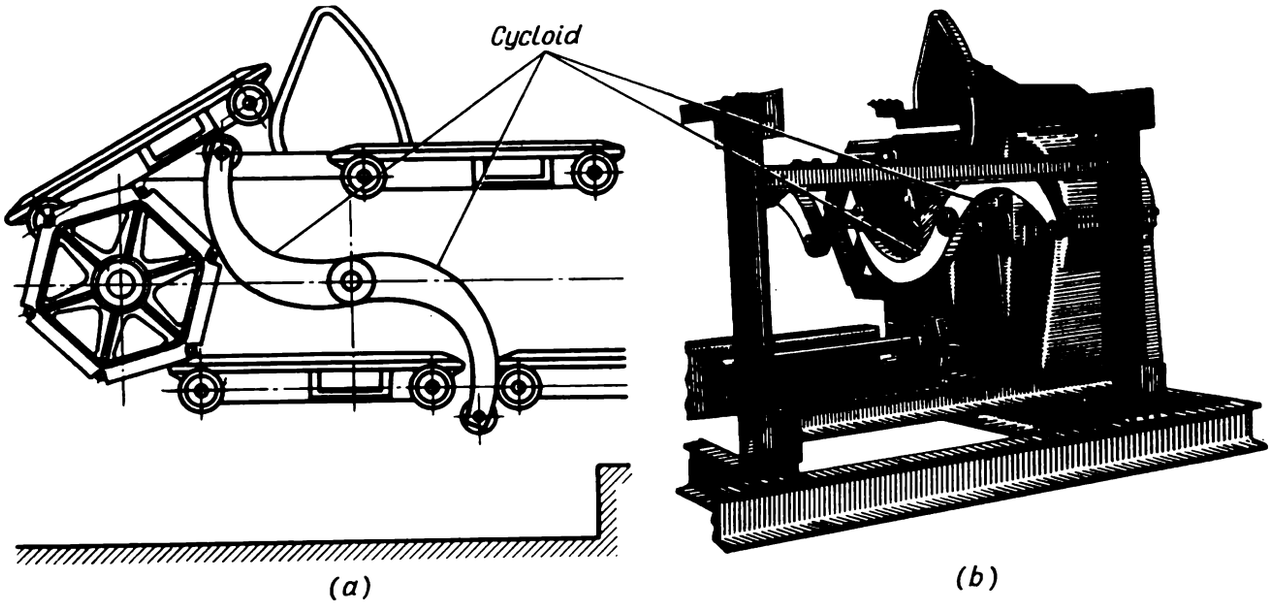


Fig. 109

the guiding circle 12 divisions, each one equal to 1/12 πD. To determine the arc of the guiding circle $AA_{12}=\pi D$, use the formula $\alpha=\frac{180°D}{R}$.

The angle α thus obtained is divided into 12 equal parts with the aid of a protractor and the points are denoted as *1′* through *12′*. From O_0 and through these points draw radial lines whose extensions will intersect the auxiliary arc at points O_1 through O_{12}. With O_0 as a centre describe a series of auxiliary arcs passing through the points of division of the rolling circle.

From O_1 through O_{12} as centres and with a radius equal to $\frac{D}{2}$ describe arcs to intersect the corresponding auxiliary arcs at points A_1 through A_{12}. A smooth curve is then drawn through these points to obtain the required epicycloid.

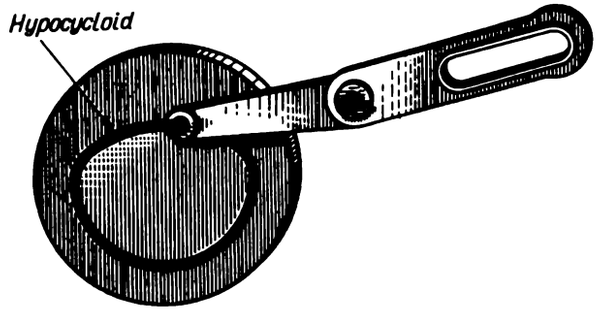


Fig. 110

To draw the hypocycloid, see Fig. 108*c*. The construction of the hypocycloid is quite similar to that of the epicycloid.

Describe a rolling circle of diameter D and a guiding circle of radius R tangent to it at point A. Divide the angle α (which is equal to $180\ \frac{D}{R}$) and the rolling and guiding circles into 12 equal parts. From O_0 and through the points of division on the guiding circle draw radial lines which will intersect the auxiliary circle of radius $R-\frac{D}{2}$ at points O_1 through O_{12}.

With O_0 as a centre describe auxiliary arcs passing through the points of division of the rolling circle.

From O_1 through O_{12} as centres and with a radius equal to $\frac{D}{2}$ draw arcs to intersect the corresponding auxiliary arcs at the points A_1 through A_{12} of the required hypocycloid.

An example of practical application of the hypocycloid is given in Fig. 110. Presented in the figure is a flat disk cam for automatic metal-cutting machine tools. At certain places the grooves for the lever pins follow a hypocycloid.

Questions

1. What are the laws governing the generation of the spiral of Archimedes and sinusoid?
2. What are the conic sections?
3. What is the difference between the cycloid, the epicycloid and the hypocycloid?

Exercise 12

1. Draw an ellipse with a major axis of 100 mm and a minor axis of 70 mm.
2. Draw a spiral of Archimedes given its pitch $S=40$ mm.

Exercise 13

1. Draw the involute of a circle 50 mm in diameter.
2. Draw a parabola having $p=30$ mm.

Exercise 14

1. Draw an equilateral hyperbola from the coordinates of one of its points: $x=20$ mm, $y=90$ mm.
2. Draw a sinusoid given $D=46$ mm and $L=120$ mm.

III

FUNDAMENTALS OF DESCRIPTIVE GEOMETRY AND PROJECTION DRAWING

CHAPTER 1

GENERAL

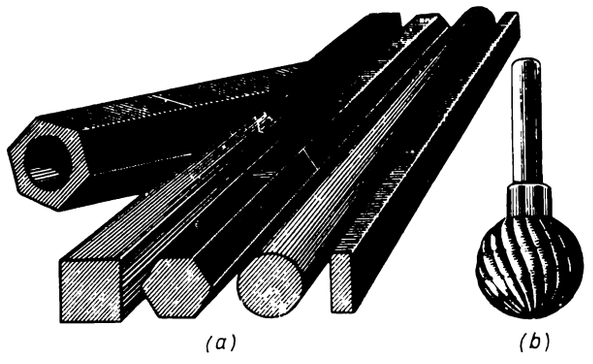
This part deals with the various methods of representing three-dimensional objects in a drawing, i.e., on a plane.

Projection drawing is based on descriptive geometry which is also called the theory of drawing. A drawing made according to the rules of descriptive geometry serves as a document to which separate machine parts are manufactured and then assembled into a single unit.

Engineering drawing is based on projection drawing, which studies practical methods of representation of geometrical solids and their combinations, various objects, parts of machines, instruments, and apparatus.

The shape of an object, no matter how complicated, can always be rendered as a combination of simple geometrical solids or parts thereof. The most common surfaces forming various mechanical parts are: planes, surfaces of revolution (cylindrical, conic, spheric, and tore) and helicoidal surfaces. Shown in Figs. 111 and 112 are rolled stock, a rotary file and a machine part bounded by simplest geometrical surfaces. In the case of rolled stock (Fig. 111*a*) we have the following plane figures: rectangles (square included), circles, hexagons, and a surface of revolution, a cylinder. The rotary file (Fig. 111*b*) is a combination of a cylindrical, a spherical and a tore surface. The handle in Fig. 112 has three spherical surfaces *a*, two conic surfaces *b*, a cylindrical surface *c*, a shaped surface of revolution *d*, and a helicoidal surface *e* (the threaded end of the handle).

Projection drawing is especially important for developing three-dimensional visualization and



(*a*) (*b*)

Fig. 111

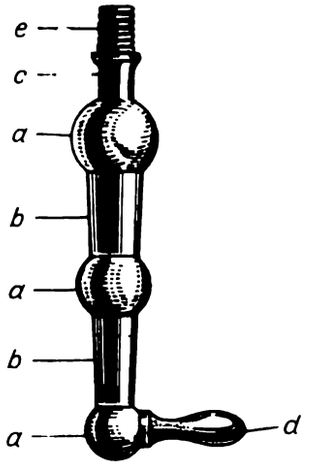


Fig. 112

habits of logical reasoning. To be able to read complicated drawings and make drawings of various machine parts and their assemblies the student must make a profound study of the fundamentals of projection drawing.

This should be accompanied by a great number of exercises. Only in this way is it possible to master the rules and methods of projection drawing.

1. METHODS OF GRAPHIC REPRESENTATION

The representation on a plane of any three-dimensional object placed in front of this plane is called the *projection* of this object on the given plane. The word projection is of Latin origin and means "to throw forward"; thus the projection is a view of an object "thrown" onto a plane by means of straight lines, or rays, which are usually drawn through definitive or significant points of the object up to where they pierce the plane. The points at which the rays intersect with the plane are called the projections of the points and the plane is called the *plane of projection.* If all the rays, called the *projecting lines*, or *projectors*, issue from one point O, then the projection of the object on the plane of projection is called the *central projection* of this object. Here is an example. The central projection of the file in Fig. 113*a* is obtained in the following way: from the point O, which is called the *centre of projection*, draw a series of projecting lines through all the definitive points of the file, B, C, D, E, F, M, and extend them to intersect the plane of projection at the points b, c, d, e, f, m. Joining the latter points on the plane we obtain the central projection of the file. But, as is obvious from the picture, the dimensions of the file projected in such a way are enlarged.

Such a view renders the shape of an object but is rather inconvenient as regards determining its true size and dimensioning its drawing.

That is why central projections rarely find application in engineering drawing, where *axonometric projections* are preferred.

To construct the axonometric projection of an object (say, the same file) proceed as follows. Again place the file in front of the plane of projection V (see Fig. 113*b*) and draw a series of projecting lines, but this time parallel to each

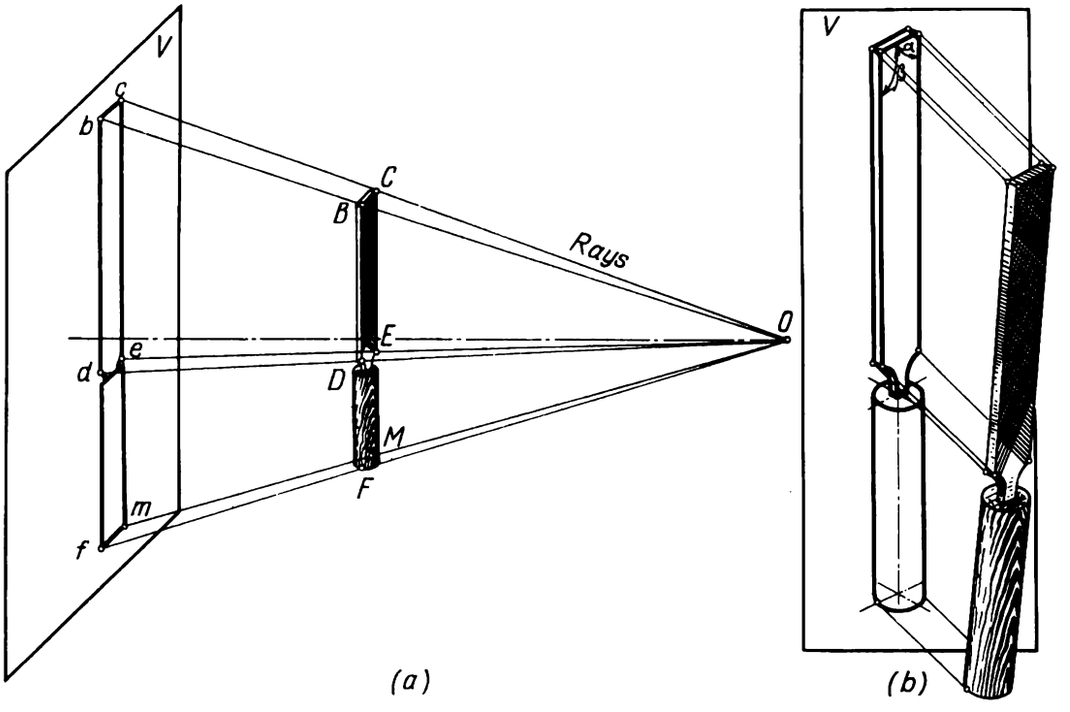


Fig. 113

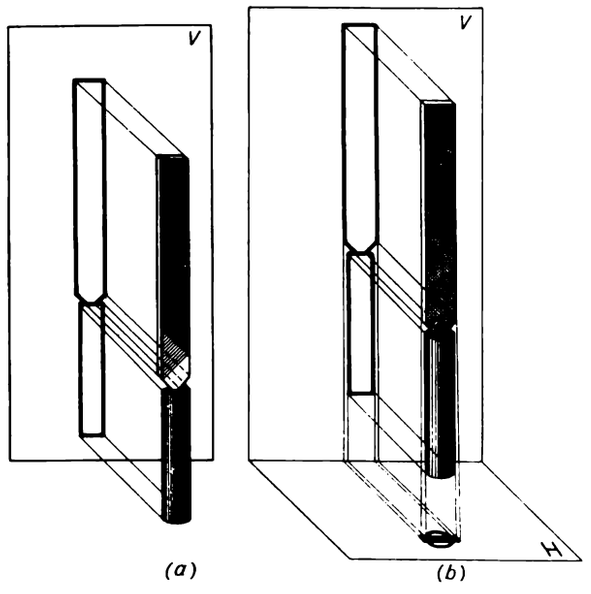


Fig. 114

other, as if the centre of projection is removed to infinity from the plane of projection.

Axonometric projection provides a clear but distorted representation: right angles α and β are seen as acute and obtuse angles, circles are projected as ellipses, etc. (see Fig. 113*b*).

The most widespread method used in machine drawing is *orthographic projection*. All working drawings of individual parts of machines, units, devices, instruments, etc. are made using orthographic projections with all projecting rays parallel to each other. In orthographic projection it is customary to place the principal edges and faces of the object parallel to the plane of projection, as illustrated by the file in Fig. 114*a*. Then its faces, corners, and edges will be projected on the plane V undistorted, that is in true size.

Since such a representation of the file is incomplete (its thickness is not shown), two or three planes of projection perpendicular to each other are used to obtain an orthographic projection.

Such an arrangement (Fig. 114*b*) makes it possible to represent the shape and all the dimensions of an object.

CHAPTER 2

PROJECTIONS OF A POINT

1. PROJECTING A POINT ON TWO PLANES OF PROJECTION

Each complicated shape of a machine part, tool or any other object may be thought of as divided into separate parts bounded by simple geometrical surfaces (planes). A plane is generated by a straight line moving in space (see Fig. 115*b*). Any section of a straight line may be visualized as the path of a moving point (see Fig. 115*a*).

Thus, to make a drawing of an object as a whole we must first study the rules and methods of constructing the projections of its elements.

The simplest geometrical element is a point. That is why the studies of orthographic projections of objects begin with the orthographic projection of a point.

Fig. 116*a* shows a dihedral angle formed by two mutually perpendicular planes of projection (the vertical V and the horizontal H) with ox as the axis of projection. The edges oz and oy are perpendicular to ox.

The vertical plane of projection V is represented as a rectangle, the horizontal plane H as a parallelogram whose side oy is drawn at an angle of 45° to ox.

Now let us place a point A in this dihedral angle and construct its projections. To this end, from the point A drop perpendiculars to the planes V and H. The points of intersection a'

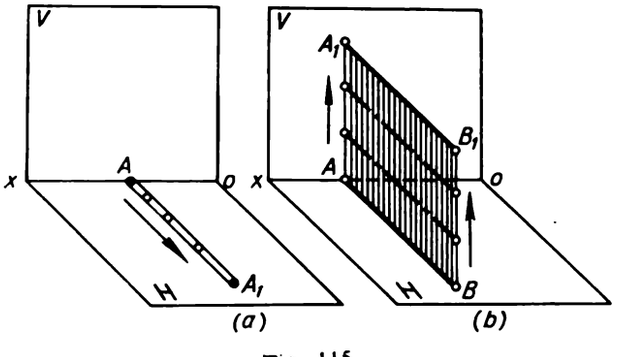


Fig. 115

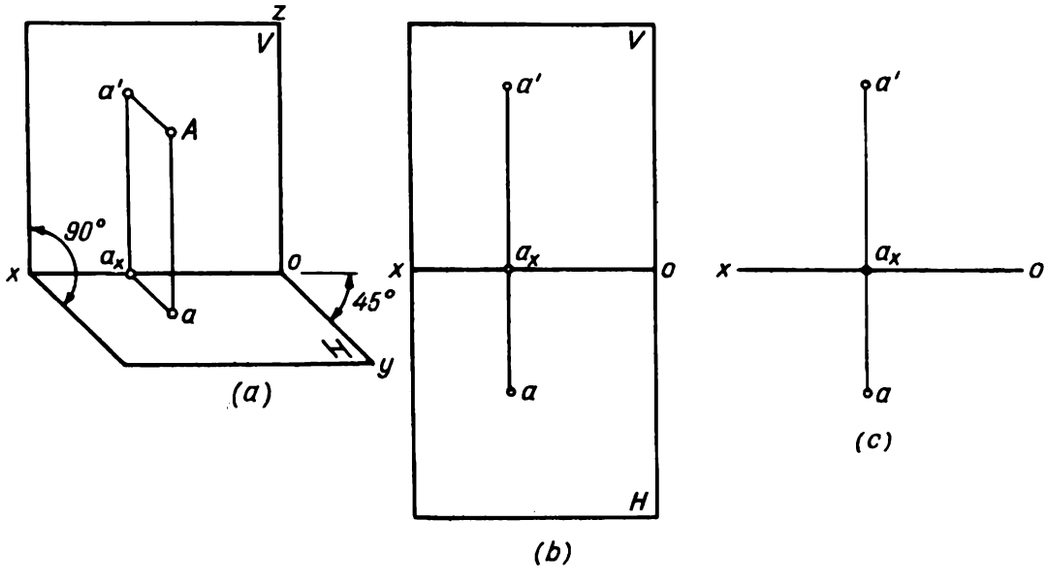


Fig. 116

and a of the perpendiculars with the planes of projection V and H respectively are called the orthographic or orthogonal projections of the point A.

The figure Aaa_xa' is a rectangle, its sides aa_x and Aa' being half their true size.

Now let us revolve plane H about ox until it becomes the extension of plane V. Thus we obtain an orthogonal drawing of point A (see Fig. 116*b*).

To simplify the drawing, the two planes of projection are usually not shown (Fig. 116*c*).

The perpendiculars drawn from the point A to the planes of projection are called the *projecting lines;* the point a' is called the *vertical projection* of A, a being its *horizontal projection.*

2. PROJECTING A POINT ON THREE PLANES OF PROJECTION

The basic purpose of a multi-view projection is, of course, to show the true size and shape of the object being represented. If two projections are not sufficient, the object is projected on three planes. In this case a third plane of projection W is added, which is perpendicular to both planes, V and H, and is called the *profile plane of projection* (Fig. 117*a*). The third projection of the point A, which is called the profile projection, is obtained in a similar way: from A drop a perpendicular to the plane W at point a''.

To obtain the complete orthographic representation of the point A shown in Fig. 117*c*

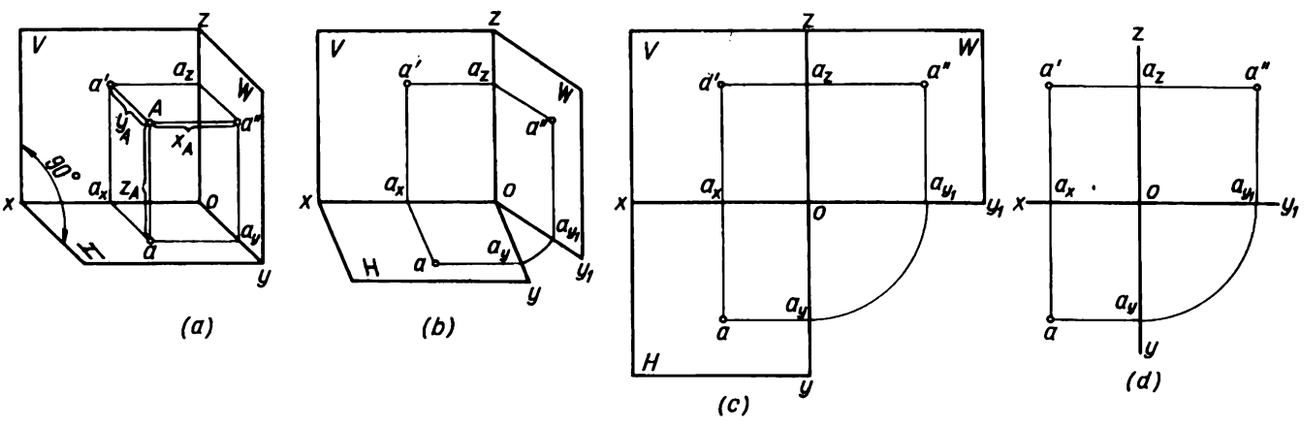


Fig. 117

and d, revolve the plane H downward about ox and the plane W to the right about oz (Fig. 117*b*) until they become extensions of the plane V (Fig. 117*c*).

The axes of an orthographic projection are always designated as ox, oy, and oz. The point of their intersection (origin of coordinates) is designated as the letter o.

3. COORDINATES OF A POINT

Sections of the projecting lines from the point A to the planes of projection are called the coordinates of this point and are denoted by x_A, y_A, and z_A. For example, the coordinate z_A of the point A equal to the length $a'a_x$ (see Fig. 117*a*) is the distance between the point A and the horizontal plane of projection H. Likewise, the coordinate y_A of the point A equal to the length aa_x is the distance between the point A and vertical plane of projection V; and the coordinate x_A equal to the length aa_y is the distance between the point A and the profile plane of projection W.

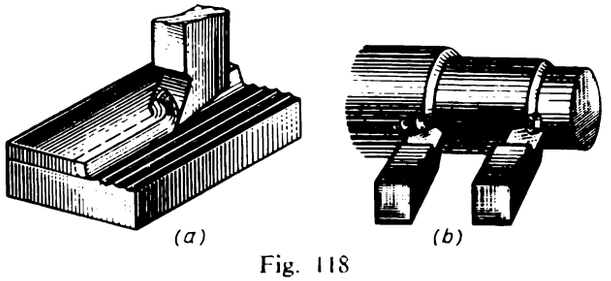


Fig. 118

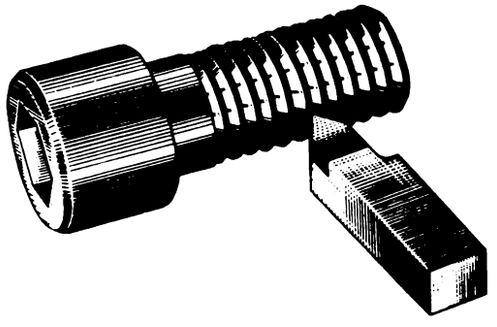


Fig. 119

Let us consider an example from practical engineering. The main means for machining metal parts is the single-point tool (Fig. 118). It is used for planing flat parts (Fig. 118*a*), turning mechanical parts in the shape of cylindrical, conic and other bodies of revolution (Fig. 118*b*), and cutting threads (Fig. 119).

Examining the thread tool from the geometrical point of view, we see that it is bounded by a number of faces representing various plane figures, most of them being polygons. They intersect with each other to produce edges (line-segments). Adjoining edges intersect at points.

Let us now place the tool within the dihedral angle formed by two mutually perpendicular planes of projection: the vertical V and horizontal H (the tool lies on the plane H, touching the plane V). For the sake of convenience let us "cut off" a portion of the tool shank. Now we shall make a drawing of this tool.

To begin with, construct orthographic projections of its point (A in Fig. 120*c*) by dropping perpendiculars to the planes of projection V and H at a' and a (see also Fig. 120*a* with the tool removed). These are the orthographic projections of point A. Its coordinates, z_A and y_A, indicate the distances between the tool point

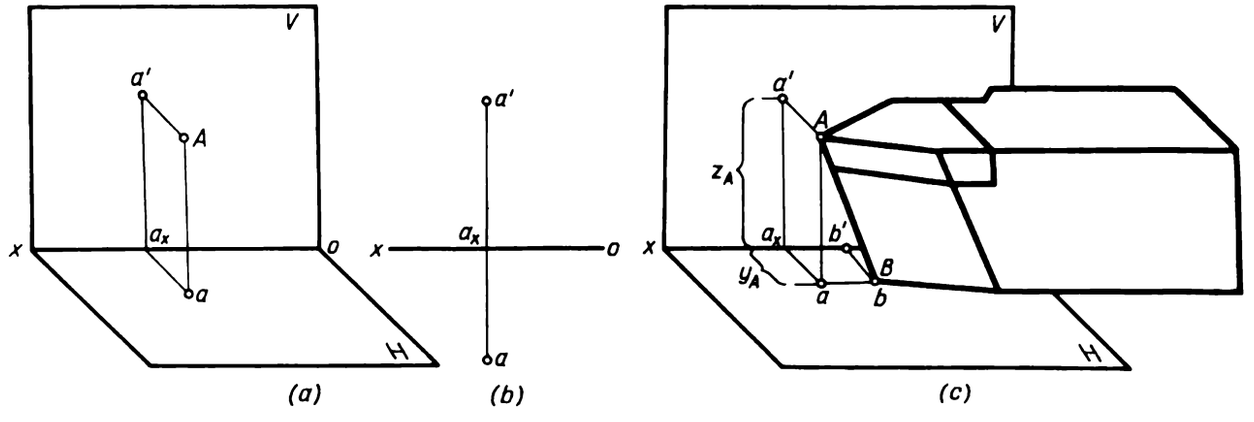


Fig. 120

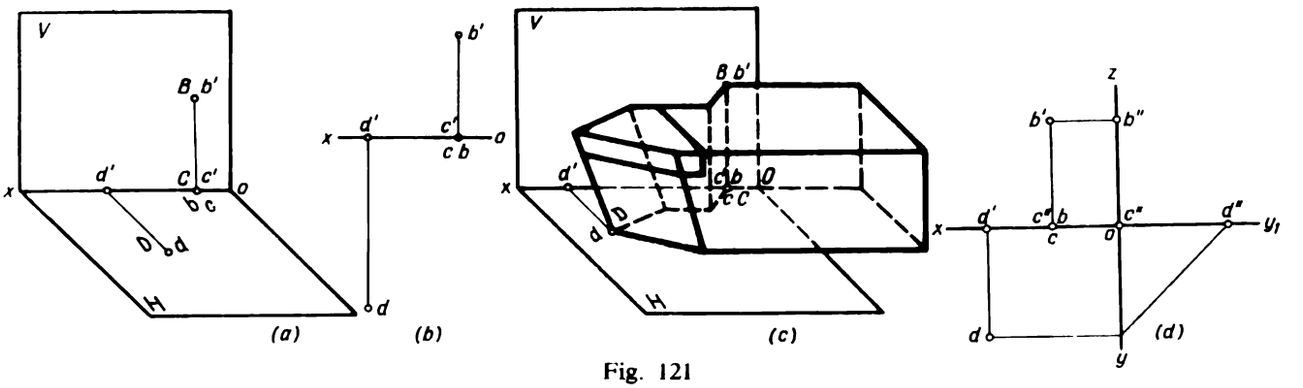


Fig. 121

and the planes of projection H and V respectively (see Fig. 120*c*). The complete orthographic representation of point A is given in Fig. 120*b*.

Since point B of the edge AB is located on the plane H, its coordinate z_B is equal to zero; the coordinate y_B indicates the distance between point B and the plane of projection V.

4. RELATIVE POSITIONS OF PROJECTIONS OF POINTS IN A DRAWING

Relative positions of the projections of a point in a drawing depend on the location of this point with respect to the planes of projection.

If point D is situated on the horizontal plane of projection H (see Fig. 121*a* and *c*), its vertical projection d' lies on the axis ox.

The horizontal projection b of the point B located on the vertical plane of projection also lies on the axis ox.

The horizontal and vertical projections, c and c' respectively, of the point C located on the axis ox coincide with the point itself, i.e., they also lie on the axis ox.

Fig. 121*b* shows the points D, B, and C projected on two planes, V and H, while Fig. 121*d* presents the same points projected on three planes, V, H, and W.

From Fig. 121*d* it follows that:

point D located on the horizontal plane of projection has its profile projection on the axis oy_1;

point B located on the vertical plane of projection has its profile projection on the axis oz;

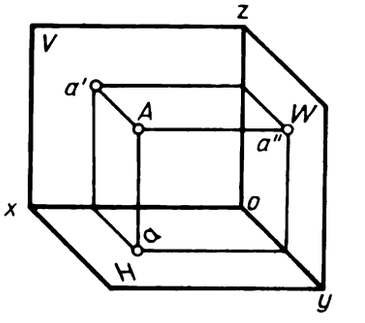
point C located on the axis ox has its profile projection at the origin of coordinates (point o).

Questions

1. What is the difference between central and parallel projection?
2. What are the coordinates x, y, and z of a point?
3. What is the orthographic projection of an object?
4. Where are the projections of a point located in an orthographic representation?
5. What is the position of a point in space if its horizontal projection is on the axis of projection ox?
6. What is the sequence of finding the profile projection of a point with its horizontal and vertical projections given?
7. How are the distances between a point and the planes of projection determined, given the orthographic projections of this point?

Exercise 15

Construct three projections of point A given its coordinates (see table of Fig. 122).



Task No.	x	y	z
1	10	12	14
2	20	15	0

Fig. 122

CHAPTER 3

PROJECTING A STRAIGHT LINE

1. PROJECTING A STRAIGHT LINE ONTO TWO AND THREE PLANES OF PROJECTION. PROJECTING PLANE

Any straight line* AB is determined by two points taken at its ends.

To construct the orthographic projection of AB on the horizontal plane of projection, we can use two methods.

The first method (Fig. 123*a*). Drop perpendiculars from the points A and B onto plane H, intersecting this plane at points a and b which are the horizontal projections of the points A and B. By joining the points a and b with a straight line we obtain the required horizontal projection of AB.

The second method (Fig. 123*b*). Take a series of points (A, C, D, E, B) on the given straight line AB. Drop perpendiculars from each of these points onto the plane H. All these perpendiculars taken together can be considered as a plane Q which is perpendicular to the plane of projection H. The plane Q will intersect plane H to form a straight line on which the points of intersection of all the perpendiculars with the plane H are located. Since these points are the horizontal projections of the points on AB, the length $acdeb$ will be the horizontal projection of AB. Thus, the projection of the straight line AB on the plane H can be obtained by passing through AB a plane Q perpendicular to the plane H to intersect the latter. The line of intersection of the two planes will be the required projection of AB. The plane Q is called the *projecting plane*.

If it is perpendicular to the horizontal plane of projection, then it is called the *horizontal projecting plane*. If plane Q is perpendicular to the vertical plane of projection, it is called the *vertical projecting plane* (Fig. 123*c*). If plane Q is perpendicular to the profile plane of projection, it is called the *profile projecting plane*.

2. RELATIVE POSITIONS OF PROJECTIONS OF A STRAIGHT LINE IN DRAWINGS

Let us consider various positions of a straight line relative to the planes of projection H, V and W.

As an example we shall take a thread tool once again.

I. Place the tool with its longer edges parallel to the planes H and V (Fig. 124*c*). In this case the edge AB will be a straight line perpendicular to the plane V. Such a line is called the *vertical projecting line* (see also Fig. 124*a*). As is obvious from the orthographic drawing of the straight line AB (Fig. 124*b*), its horizontal projection ab

* Here and further in the text any section of a straight line will be referred to simply as a straight line for brevity.

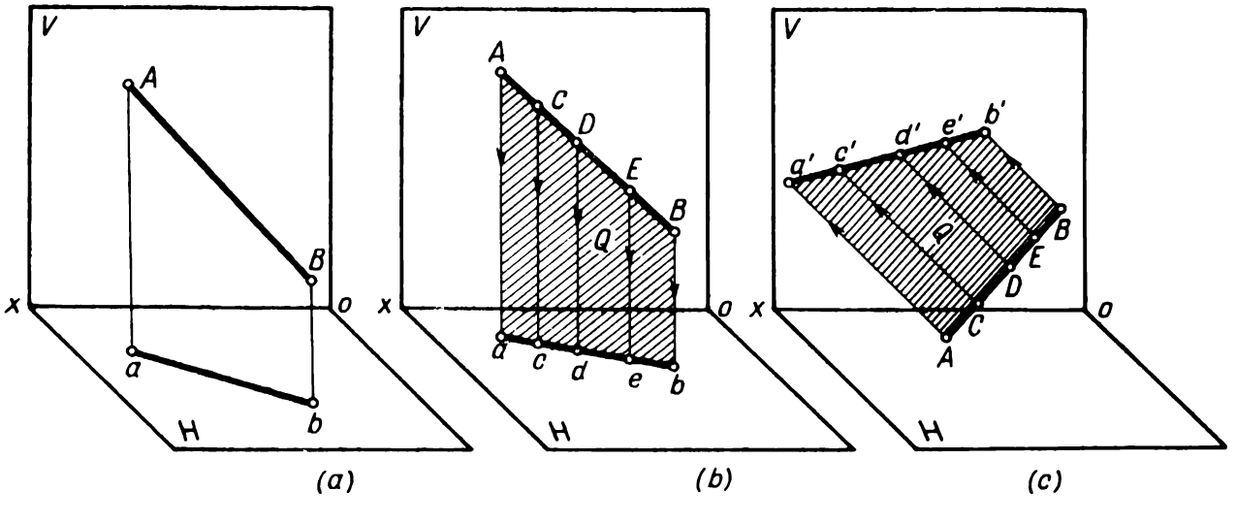


Fig. 123

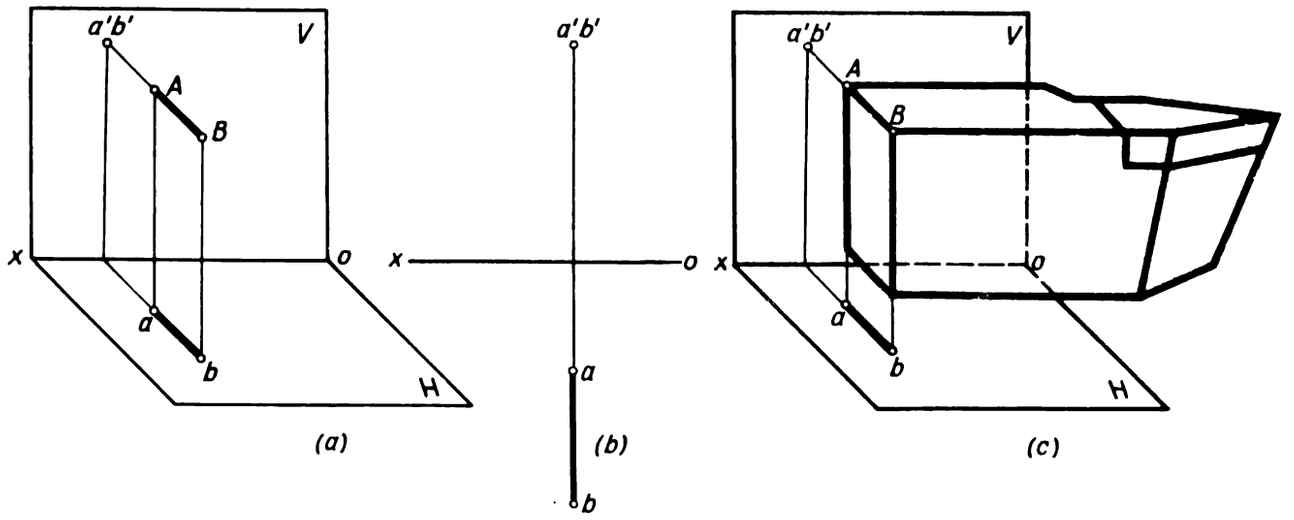


Fig. 124

is perpendicular to the axis *ox* and equal to *AB* in length, while its vertical projection *a'b'* is a point.

II. The edge *BC* of the tool is perpendicular to the plane *H* (Fig. 125*c*). *BC* is called the *horizontal projecting line* (see also Fig. 125*a*). As is seen from the orthographic representation of *BC* (Fig. 125*b*), its vertical projection *b'c'* is perpendicular to the axis *ox* and equal to *BC* in length, its horizontal projection *bc* being a point.

III. Consider the edge *AB* in Fig. 126*c* which is the cutting edge of the tool. It is parallel to the horizontal plane of projection. Such a line is called a *horizontal line* (see also Fig. 126*a*). Referring to the orthographic drawing of the horizontal line *AB* (Fig. 126*b*), we see that its vertical (*a'b'*) and profile (*a''b''*) projections are parallel to the axes of projection *ox* and oy_1, respectively, whereas its horizontal projection *ab* is situated at an angle to the axis *ox* and is equal to the length of *AB*.

IV. The edge *AB* in Fig. 127*c* is parallel to the plane *V*. A straight line parallel to the vertical plane of projection is called a *vertical line* (see also Fig. 127*a*).

The drawing of the vertical line *AB* (Fig. 127*b*) shows that the horizontal projection of *AB* is parallel to the axis *ox*. The vertical projection of *AB* is inclined to the axis *ox* and is the true length of the vertical line *AB*. The profile projection of *AB* is parallel to the axis *oz*.

V. The longer edge *AB* in Fig. 128*c* is parallel to the axis *ox*. Such a straight line is called a

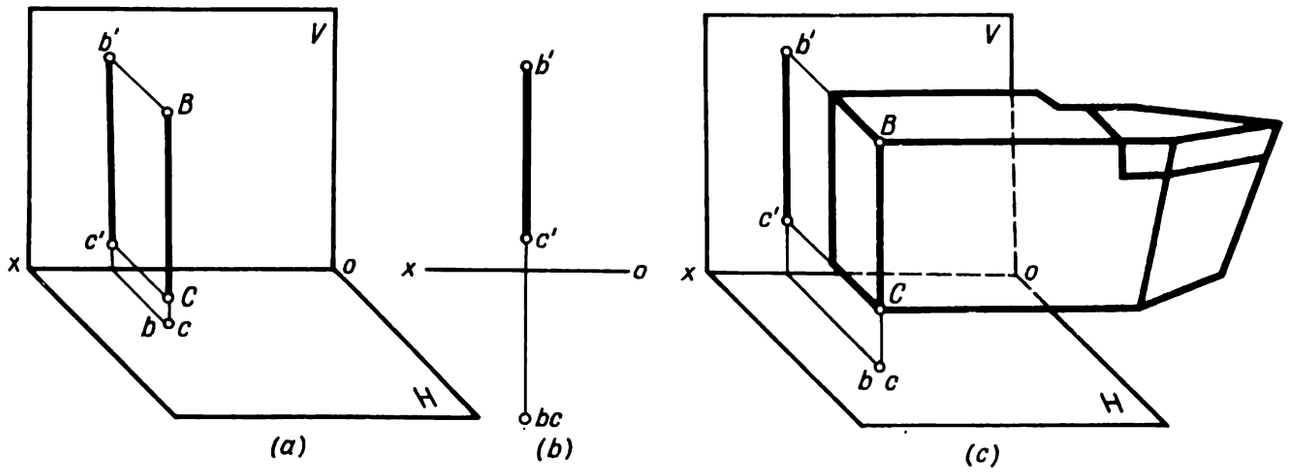


Fig. 125

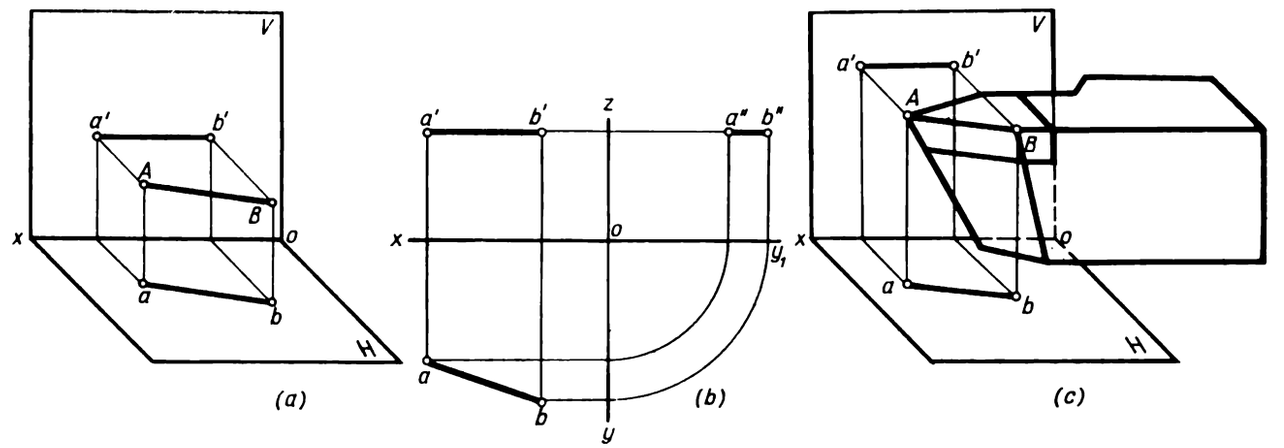


Fig. 126

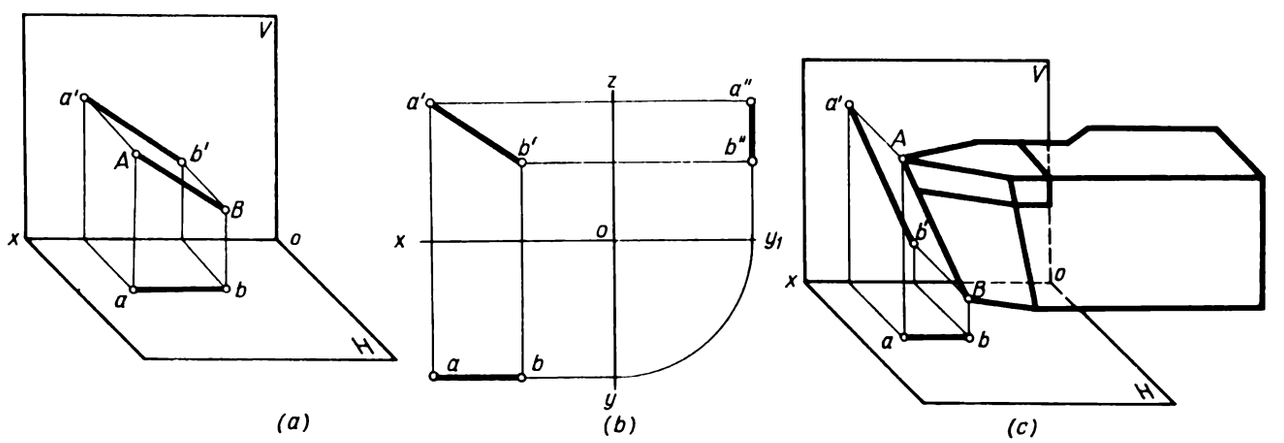


Fig. 127

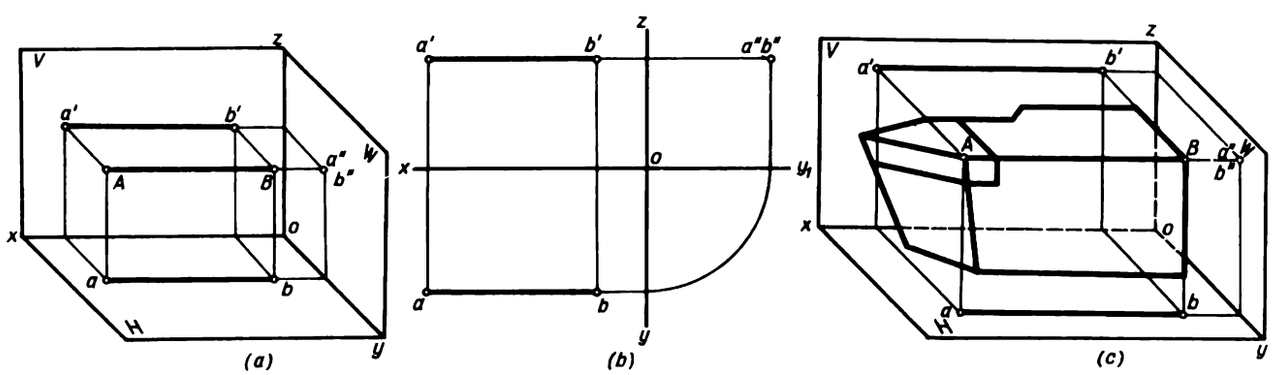


Fig. 128

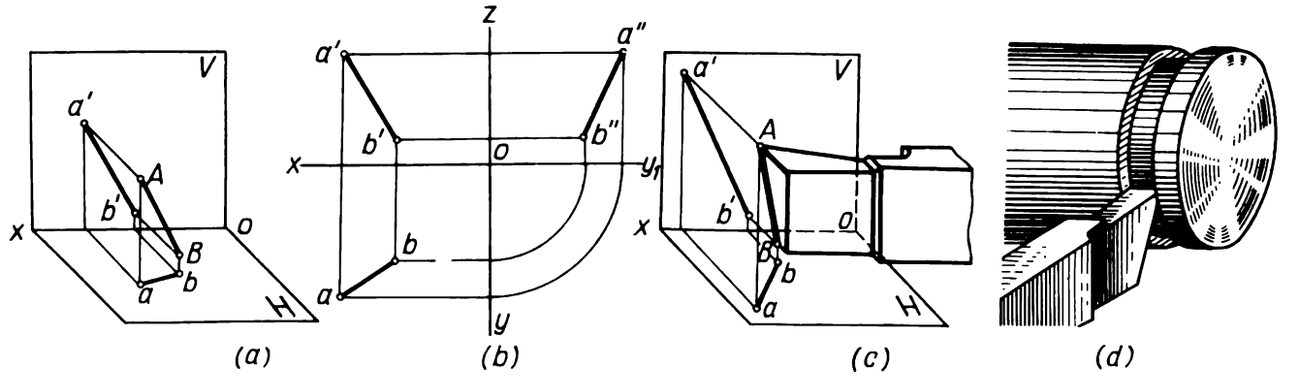


Fig. 129

profile projecting line (see also Fig. 128*a*). Both vertical and horizontal projections of this edge are parallel to the axis *ox* and are the true length of *AB* (Fig. 128*b*). The profile projection of *AB* is a point.

A straight line which is neither parallel, nor perpendicular to the planes of projection, i.e., is inclined to each of them, is called a *line of general position.* Sometimes it is called a *line of random position.*

Let us take a line *AB* of general position (Fig. 129*a*) and construct its horizontal and vertical projections using the first method (see Fig. 123*a*). The lines *ab* and *a'b'* will be the two respective projections of *AB*.

An example illustrating the construction of projections of a line of general position is shown in Fig. 129*c*. Shown in Fig. 129*d* is a cutting-off tool. Let us place the tool in the dihedral angle formed by the two planes of projection *H* and *V*, with its longer faces and edges parallel to these planes. The longer edges of the tool head, for instance, the edge *AB*, inclined to the planes *H* and *V*, are *lines of general position.*

Now take one edge, *AB*, and project it on the planes *H* and *V*. Then make a drawing of this line by revolving the plane *H* about the axis of projection *ox* until it becomes the extension of plane *V* (Fig. 129*b*). As with the projection of a point considered before, we notice that the respective vertical and horizontal projections of the points *A* and *B* are situated pairwise (*a* and *a'*, *b* and *b'*) on common perpendiculars to the axis *ox*.

Knowing two projections, *a'b'* and *ab*, of a line of general position, it is easy to construct the third projection, *a''b''*, following the general method.

The above discussed lines (projecting, horizontal, vertical, profile, and general-position lines) are frequently used in various drawings. That is why it is very important to remember the position of their projections with respect to the axes of projections *ox*, *oy*, and *oz*.

3. ANGLES FORMED BY A STRAIGHT LINE AND PROJECTION PLANES

Horizontal, vertical and general-position lines are situated at certain angles to the planes of projection. Thus the vertical line *AB* in Fig. 130*a* forms an angle ψ with the horizontal plane of projection *H*. Let us determine this angle.

The edge *AB* of the thread tool in Fig. 130*c* forms a certain angle ψ with the plane of its base. Since the tool's base is in the horizontal plane of projection *H*, the angle ψ is the angle formed by the line *AB* and the plane *H*.

The edge *AB* is parallel to the vertical plane of projection, that is, *AB* is a vertical line. The angle between a vertical line and the horizontal plane of projection in the drawing is equal to that between the vertical projection *a'b'* of the vertical line and the axis of projection *ox* (see also Fig. 130*b*).

Thus, from the drawing of the tool we can easily find the angle formed by the edge *AB* and the base of the tool by subtracting ψ from 180°.

4. TRACES OF A STRAIGHT LINE

The trace of a straight line (of infinite length) is the point in which this line intersects a plane of projection.

The projections of the traces of the straight line *AB* (see Fig. 131*a*) are found in the following way:

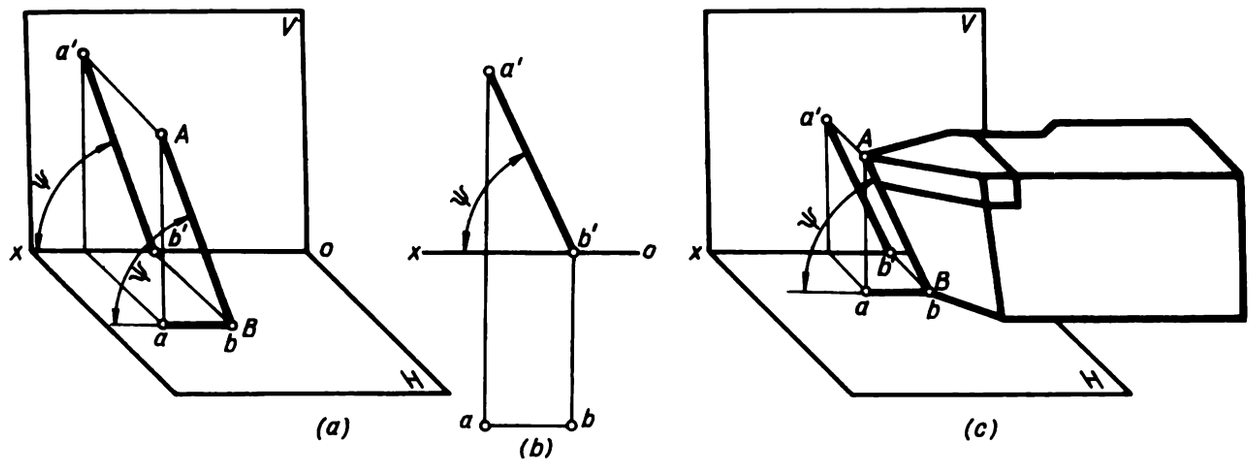


Fig. 130

1. Extend the horizontal projection *ab* and the vertical projection *a'b'* until they intersect the axis *ox* at points *v* and *m'*, respectively.

2. Erect perpendiculars to the axis *ox* at the obtained points *v* and *m'* to intersect the extensions of the respective projections of *AB* at points *v'* and *m* which will be one pair of the required traces. The points *v'* and *m* coincide with the projections of these traces on the planes *V* and *H*, respectively. The other two projections of these traces are located on the axis of projection *ox;* they have already been found — points *v* and *m'*.

Let us, for example, find the projections of the traces of the edge *AM* of the thread tool in Fig. 131*c*.

Since the tool is placed on the horizontal plane of projection, its edge *AM* is a line of general position.

Point *M* situated on the plane *H* is at the same time the horizontal trace and the horizontal projection of the horizontal trace of the straight line *AM*.

To determine the vertical trace, extend the horizontal projection *am* to intersect the axis *ox* at point *v;* then erect a perpendicular to this axis at the point *v* and find the point *v'* of intersection of this perpendicular and the extension

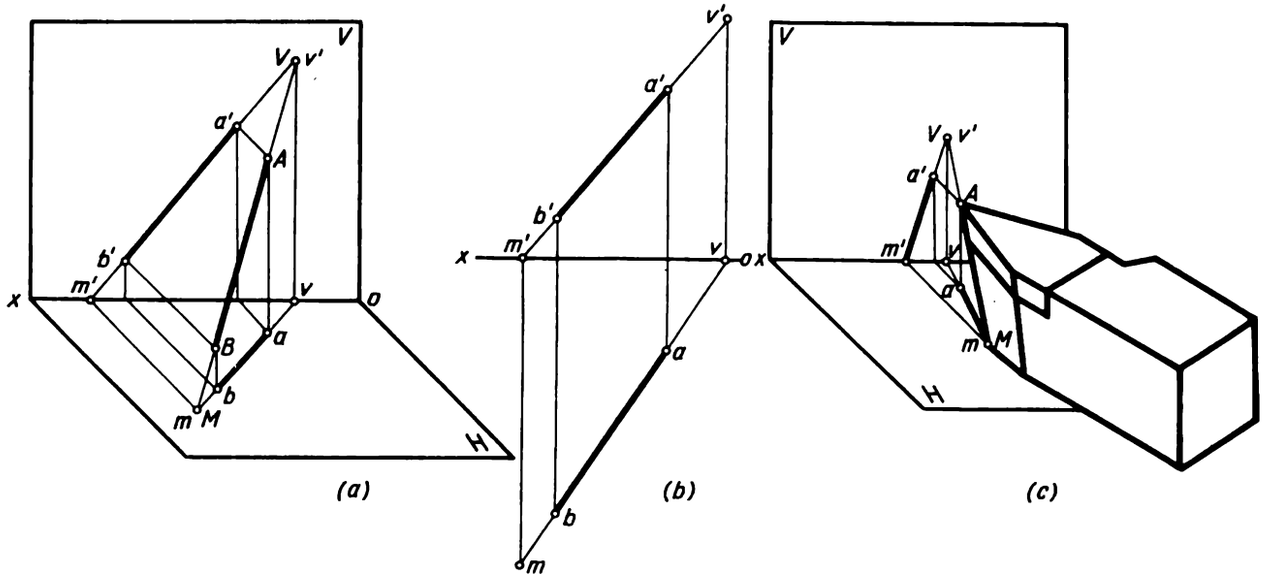


Fig. 131

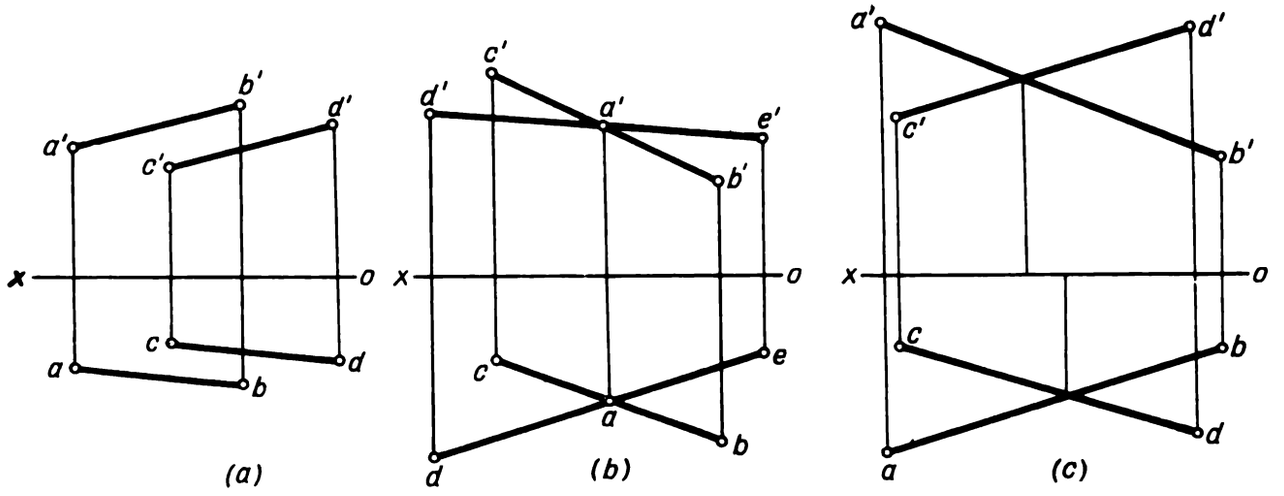


Fig. 132

of the vertical projection of AM. The point v' will be the required vertical trace of AM and simultaneously the vertical projection of the vertical trace.

All these constructions are carried out on the drawing in the following sequence (Fig. 131*c*).

Extend the horizontal projection am of AM to intersect the axis ox at point v; erect a perpendicular to the axis ox at this point; extend the vertical projection $a'm'$ of AM to intersect the perpendicular at point v'.

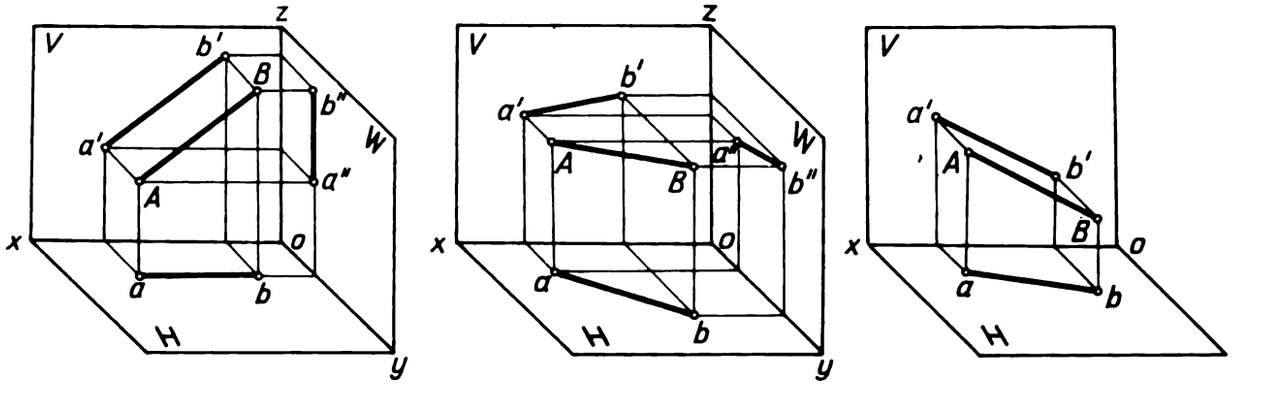
Point v is the horizontal projection of the trace V, and point v' is its vertical projection; point m is the horizontal projection of the trace M and m' is its vertical projection.

As is seen from the drawing, one of the two projections of each trace is situated on the axis of projection ox.

5. RELATIVE POSITIONS OF TWO STRAIGHT LINES

It is known from descriptive geometry that:

1. The projections of parallel lines on any plane are parallel (Fig. 132*a*).
2. If lines intersect, the points of intersection



Task No.	x		y		z	
	A	B	A	B	A	B
1	13	5	20	20	5	28
2	50	10	0	0	16	26

(a)

Task No.	x		y		z	
	A	B	A	B	A	B
1	30	10	5	30	15	40
2	40	5	0	20	0	29

(b)

Task No.	x		y		z	
	A	B	A	B	A	B
1	50	10	5	20	25	5
2	48	8	18	3	5	20

(c)

Fig. 133

of their like projections must lie on a single perpendicular to the axis *ox* (Fig. 132*b*).

3. If lines do not intersect and are not parallel to each other, then the points of intersection of their like projections do not lie on a single perpendicular to the axis *ox* (so-called skew lines, see Fig. 132*c*).

Questions

1. What are the basic positions of a straight line relative to the projection planes?
2. How are the projections of horizontal, horizontal projecting, profile and profile projecting lines situated in a drawing?
3. What is a trace of a straight line and how are projections of traces constructed on a drawing with the projections of a straight line given?
4. How many and what traces have a horizontal and a vertical line?
5. Give the definitions of parallel, intersecting and skew lines.

Exercise 16

Draw three projections of a straight line *AB* given the coordinates of the points *A* and *B* (see tables in Fig. 133*a* and *b*).

Exercise 17

Draw two projections of a straight line *AB* and find its traces with the coordinates of *A* and *B* given (see table in Fig. 133*c*).

CHAPTER 4

PROJECTING PLANE FIGURES

1. WAYS OF SPECIFYING A PLANE. TRACES OF A PLANE

Projections of a plane on a drawing will be different depending on the way it is specified. As is known from geometry, the position of a plane in space may be determined by: (1) three points not lying on one line; (2) a line and a point not lying on the line; (3) two intersecting lines; (4) two parallel lines.

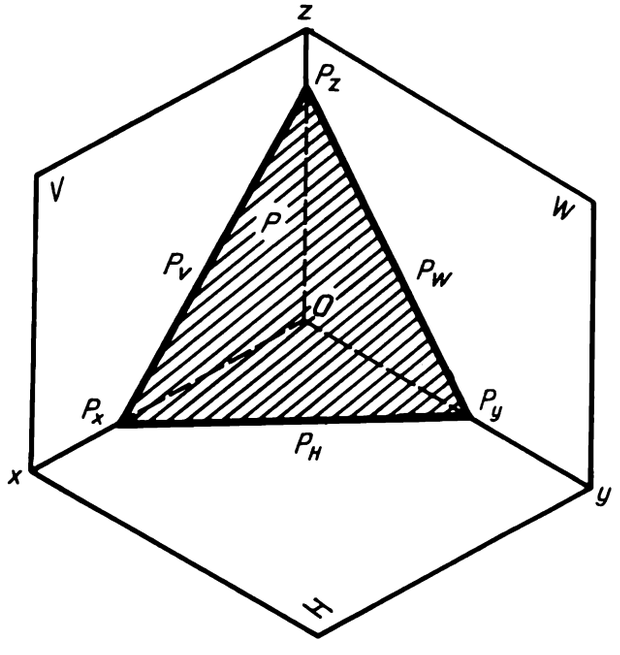


Fig. 134

In descriptive geometry and projection drawing a plane is frequently specified not by two intersecting lines arbitrarily taken on it, but by the lines along which the given plane intersects the planes of projection *H*, *V*, and *W*. These are called the *traces of the given plane.*

The line of intersection of a plane *P* and the horizontal plane of projection *H* is called the horizontal trace of the plane *P* (Fig. 134) and is designated by P_H.

The line of intersection of the plane *P* and the vertical plane of projection is called the *vertical trace of this plane* and is designated by P_V. The line of intersection of the plane *P* and the profile plane of projection is called the *profile trace of this plane* and is designated by P_W.

The traces P_H, P_V, P_W intersect in pairs on the axes of projection at points P_x, P_y, and P_z, which are called the *points of convergence.* These points may be regarded as the vertices of trihedral angles formed by the given plane and two of the three projection planes.

One of the projections of each trace of a plane coincides with the trace, and the other two projections coincide with the corresponding axes.

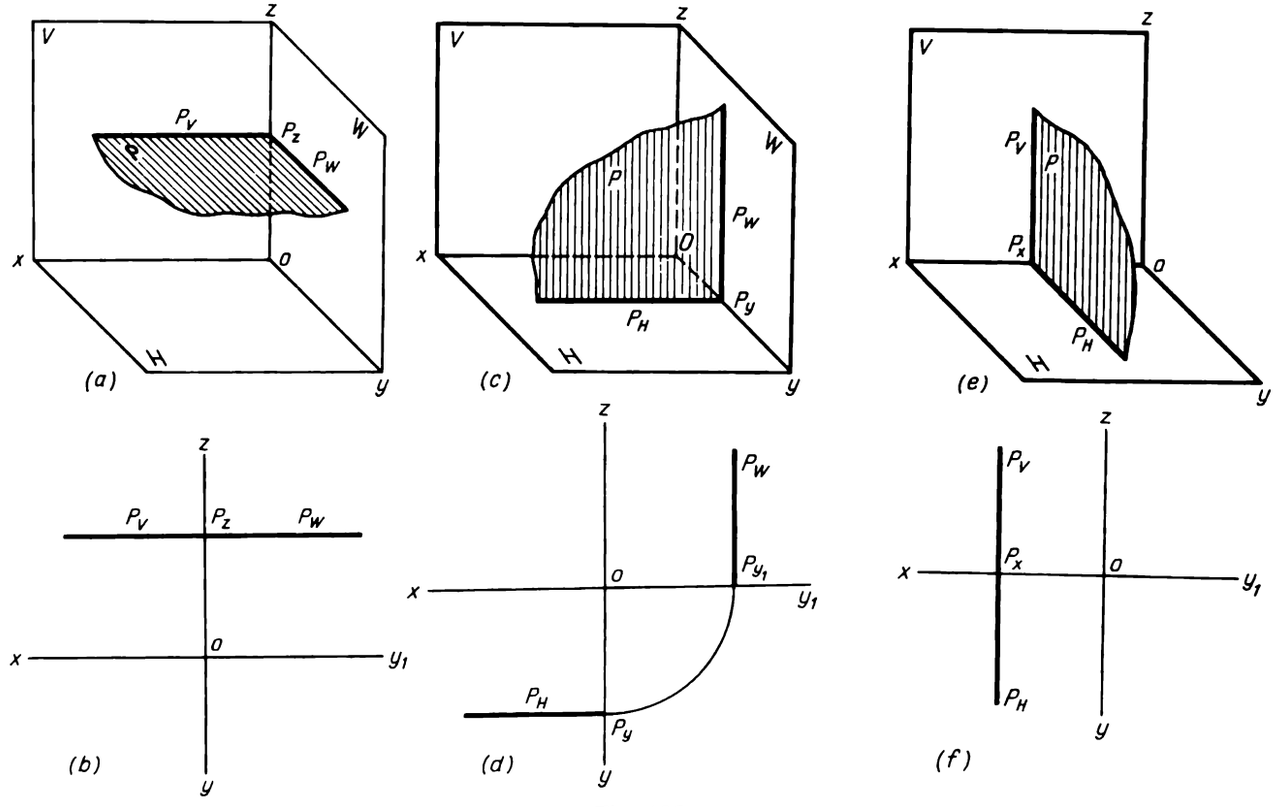


Fig. 135

For example, the horizontal trace of the plane P coincides with its horizontal projection, but its vertical projection lies on the x-axis, and its profile projection, on the y-axis. Traces of a plane P in a drawing are positioned differently relative to the projection axes, thus determining the position of the plane itself with respect to the projection planes.

For example, if a plane P has the vertical and profile traces P_V and P_W parallel to the axes ox and oy (Fig. 135*a* and *b*), then this plane is parallel to the projection plane H and is called a *horizontal plane.*

A plane P with its traces P_H and P_W parallel to the projection axes ox and oz (Fig. 135*c* and *d*) is called a *vertical plane;* and a plane P with its traces P_V and P_H parallel to the axes oy and oz (Fig. 135*e* and *f*) is called a *profile plane.*

2. PROJECTING PLANES AND OBLIQUE PLANES

If the vertical trace P_V of a plane P (Fig. 136*a* and *b*) is perpendicular to the axis ox, and the horizontal trace P_H is inclined to it, then the plane is perpendicular to the plane H and is called a *horizontal projecting plane.*

A plane perpendicular to the vertical plane of projection (Fig. 136*c* and *d*) is called a *vertical projecting plane.* Its horizontal trace is perpendicular to the axis ox, and the vertical trace is at an angle to this axis.

A plane perpendicular to the plane W (Fig. 136*e* and *f*) is called a *profile projecting plane.* The traces P_V and P_H of this plane are parallel to the axis ox.

If all the three traces P_V, P_H, and P_W of a plane P make angles with the axes ox, oy, and oz, it means that the plane is inclined to the projection planes V, H, and W at various angles, other than 90° (Fig. 137*a* and *b*). Such a plane is termed an *oblique plane*, and, in addition, an *acute-angular plane*, since the angles formed in space by the traces P_V and P_H, and P_W and P_H are acute.

The student must learn and remember the names and definitions of these planes and positions of their traces in an orthographic representation, since they will be frequently used in solving problems.

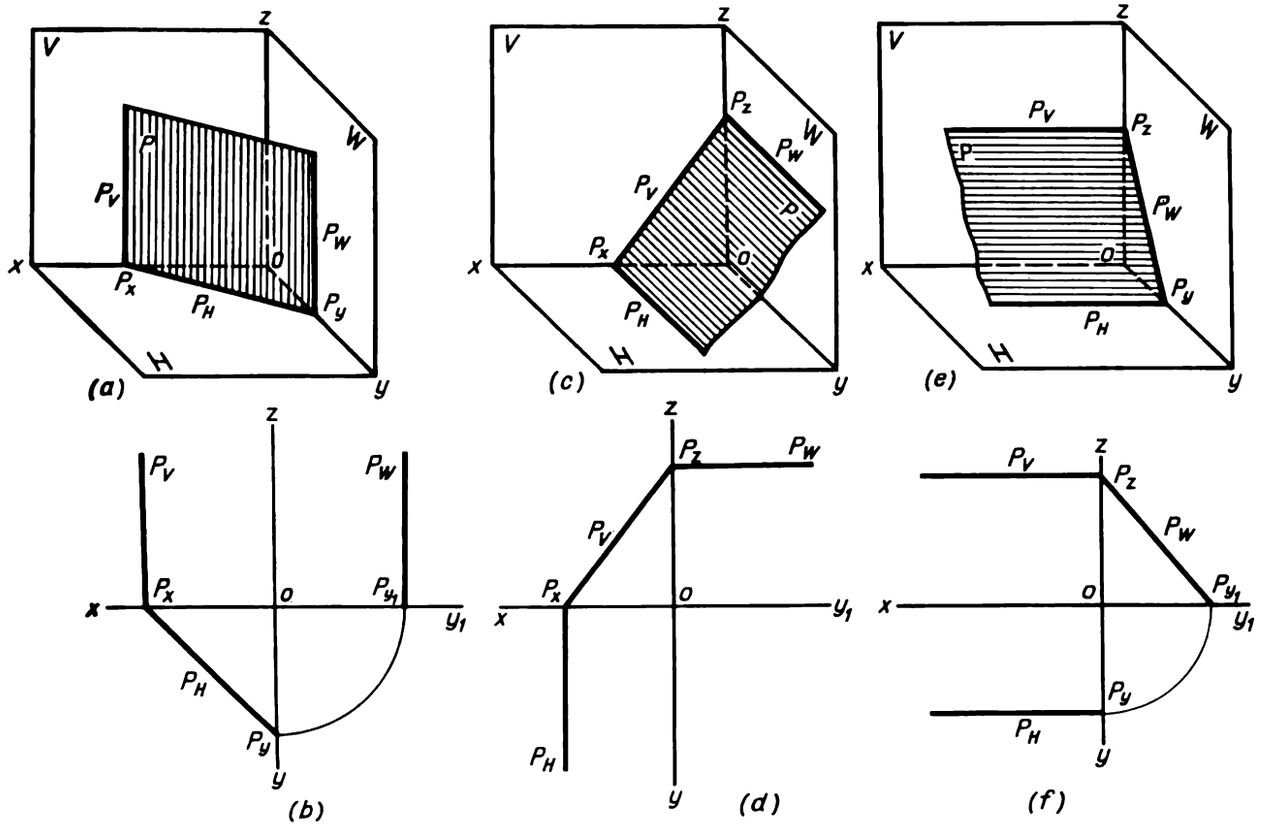


Fig. 136

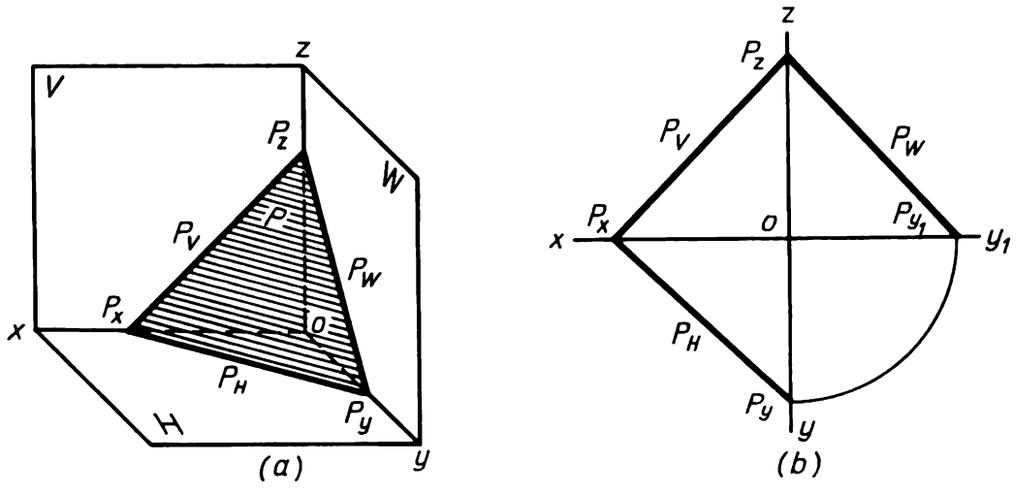


Fig. 137

3. PROJECTIONS OF POINTS AND LINES LYING ON A PLANE

As is known from geometry, if a straight line is situated on a plane, it has an infinite number of common points with the plane. These points include the traces of the line. Hence, if a line is contained in a plane, its traces lie on like traces of the plane (Fig. 138*a*).

That is why, to draw any line of general position in an orthographically represented plane specified by its traces, it is necessary to mark

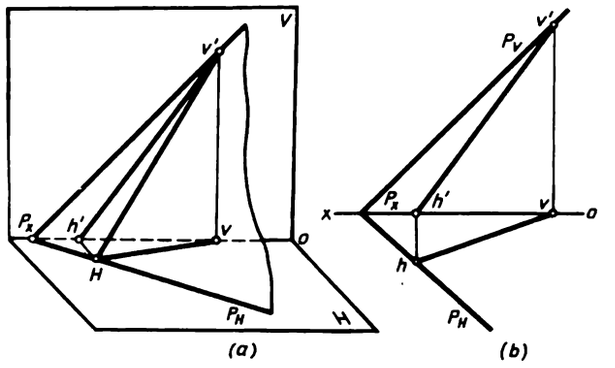


Fig. 138

points v' and h on the plane's traces (Fig. 138*b*) and consider them as traces of the required line (more precisely, v' will be the vertical projection of the vertical trace of the line, h the horizontal projection of its horizontal trace). The two other projections of the line's traces, v (the horizontal projection of the vertical trace) and h' (the vertical projection of the horizontal trace) are found by dropping perpendiculars from v' and h to the ox axis. Then join the like projections of the traces, i.e., v' to h' and v to h, to obtain two projections of the straight line contained in the oblique plane P.

Horizontal and vertical lines are often drawn on a plane, then they are called the *principal lines of the plane*. They help to solve a variety of problems in projection drawing.

In the two-plane system of projection (V and H) each of the principal lines has only one trace; thus, a horizontal line has only a vertical trace. Hence, with one trace of the principal line given, its projection is drawn in a predetermined direction.

Fig. 139*a* shows an oblique plane P and a horizontal line lying on it. As is seen from the figure, the horizontal projection of the horizontal line is parallel to the horizontal trace of the plane.

Thus, to draw orthographically any horizontal line on the plane P, proceed as follows (Fig. 139*b*):

(a) mark on the trace P_V the vertical trace of the horizontal line, v', and consider it as the vertical projection of its vertical trace;

(b) through the point v' draw a straight line parallel to the axis ox, which will be the vertical projection of the horizontal line;

(c) drop a perpendicular from v' onto ox; point v thus obtained is the horizontal projection of the vertical trace of the required line;

(d) the line va, drawn from point v parallel to the horizontal trace of the plane, P_H, will be the horizontal projection of the required horizontal line.

Horizontal and vertical lines are often drawn on projecting planes. Suppose, it is required to draw a horizontal line on a vertical projecting plane (see Fig. 140*a*). Do the following: mark the vertical trace v' of the required line (strictly speaking, the vertical projection of its vertical trace) and find its horizontal projection v (see also Fig. 140*b*) on the axis ox; then through point v draw a line parallel to P_H which will be the horizontal projection of the required horizontal line, its vertical projection coinciding with the point v'.

With the aid of the traces of lines situated on the traces of a plane containing these lines, we can pass over from specifying a plane orthographically by parallel or intersecting lines to specifying it by its traces. Fig. 141*a* illustrates a practical example of solving such a problem. Shown

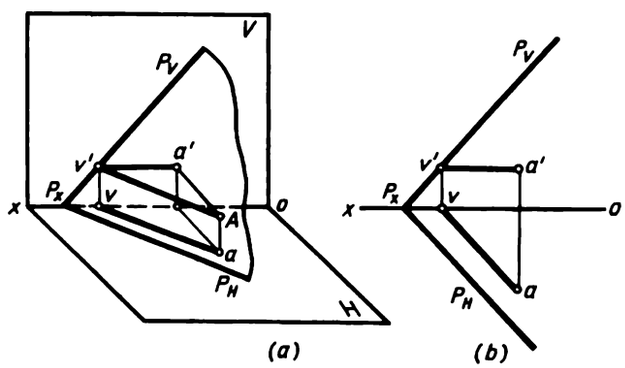


Fig. 139

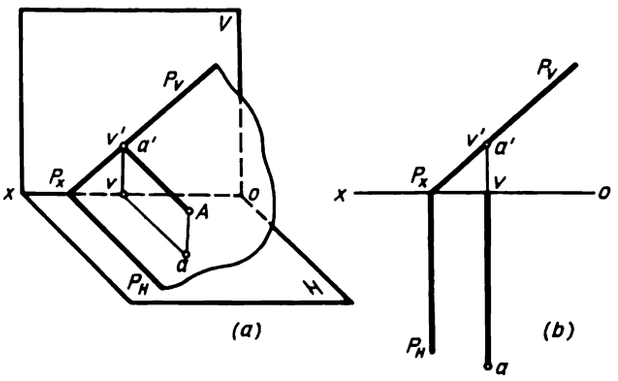


Fig. 140

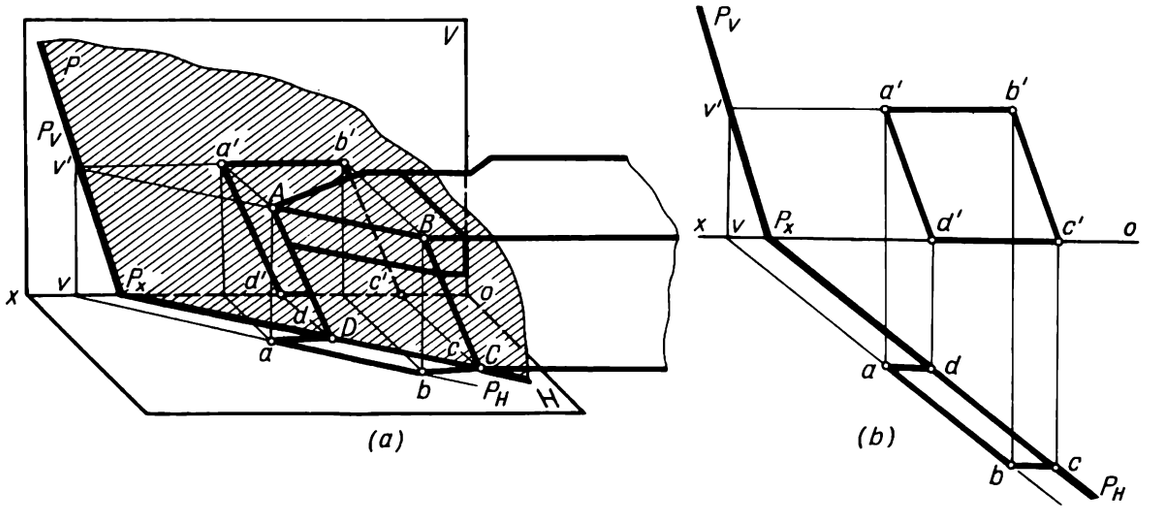


Fig. 141

in the figure is the head of a thread tool placed on the plane H. As is obvious from the drawing, the flanks of the tool are plane figures — polygons. Hence, these planes will be specified by intersecting and parallel straight lines, that is, by the sides of the polygons.

Consider the flank $ABCD$. We see that the edge DC of this flank is situated on the H plane; hence, it is the horizontal trace of the plane containing this flank (i.e., the horizontal projection of the plane's horizontal trace).

To find the vertical trace of this plane, make the following constructions (see also Fig. 141*b*). Extend the given horizontal projection dc of the line DC to intersect the axis ox at point P_x through which the required vertical trace of the plane must pass. A second point through which the required trace will pass is v', the vertical trace of the edge AB (or rather, the vertical projection of the vertical trace of this edge). This is determined by extending the given horizontal projection ab of AB to intersect the axis ox at point v which will be the horizontal projection of the required vertical trace.

The vertical projection of the vertical trace is found on the perpendicular erected to the axis ox at the point v' where the perpendicular intersects the extension of the vertical projec-

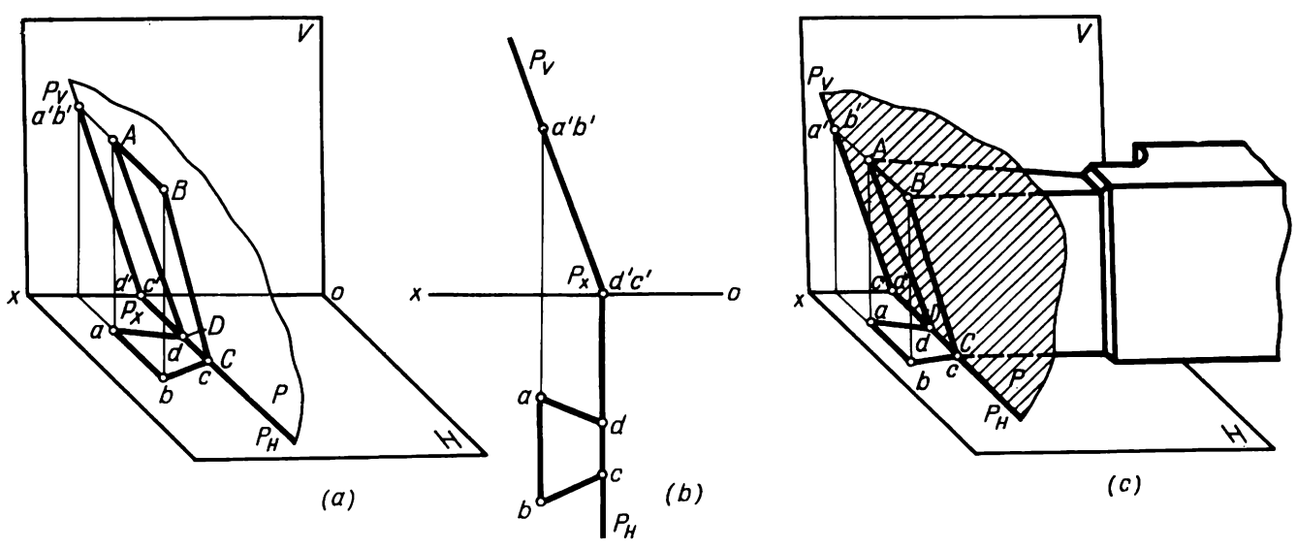


Fig. 142

tion $a'b'$ of AB. To obtain the vertical trace P_V of the plane, join the points P_x and v'.

Another example of passing over from specifying a plane by intersecting or parallel lines to specifying it by its traces is given in Fig. 142. Pictured in it is a cutting-off tool placed on the plane H (Fig. 142*c*). The flank $ABCD$ of the tool, i.e., the plane of a quadrangle, is specified either by two parallel lines AB and CD or by two intersecting lines AB and AD. This plane is perpendicular to the plane V and consequently it is a *vertical projecting plane*. Figure 142*a* presents the flank $ABCD$ graphically, while Fig. 142*b* is its orthographic drawing.

To construct the traces P_H and P_V of this plane, it is necessary that the horizontal trace P_H should pass through the horizontal projection dc of the edge DC, since this edge is situated on the plane H. The vertical trace P_V must pass through the vertical projection $a'b'c'd'$ of the flank as this flank lies in the vertical projecting plane.

Point A lying on the plane P is located on a straight line contained in this plane. Hence, to construct the projections of the point A, first it is necessary to construct the projections of the straight line and then, on its projections, to mark the projections of the point A.

In orthographic drawing one frequently encounters the following problem: with one projection of a point given, determine its two other projections. Proceed as follows (Fig. 143). Through a given projection of a point, say, the vertical projection n' of the point N, located on the plane of triangle ABC, draw the like projection of an auxiliary line in any direction (in our case $m'k'$). Then construct another projection of the auxiliary line (horizontal projection mk) by vertically projecting the points m' and k' to the points of intersection m and k of the projecting lines with the lines ac and bc. Project the point n' on mk. The profile projection n'' is found according to the general rule of projection.

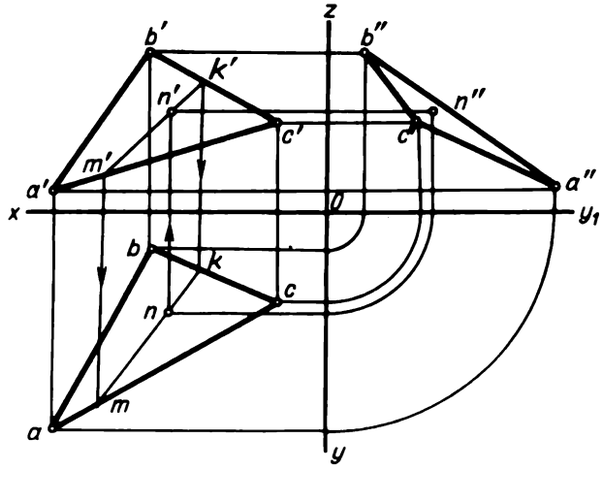


Fig. 143

If a *point is located on a projecting plane*, the construction of its projections is simplified. In this case one of its projections always lies on the like projection of the plane. For example, the horizontal projection a of point A located on a horizontal projecting plane P (Fig. 144*a*

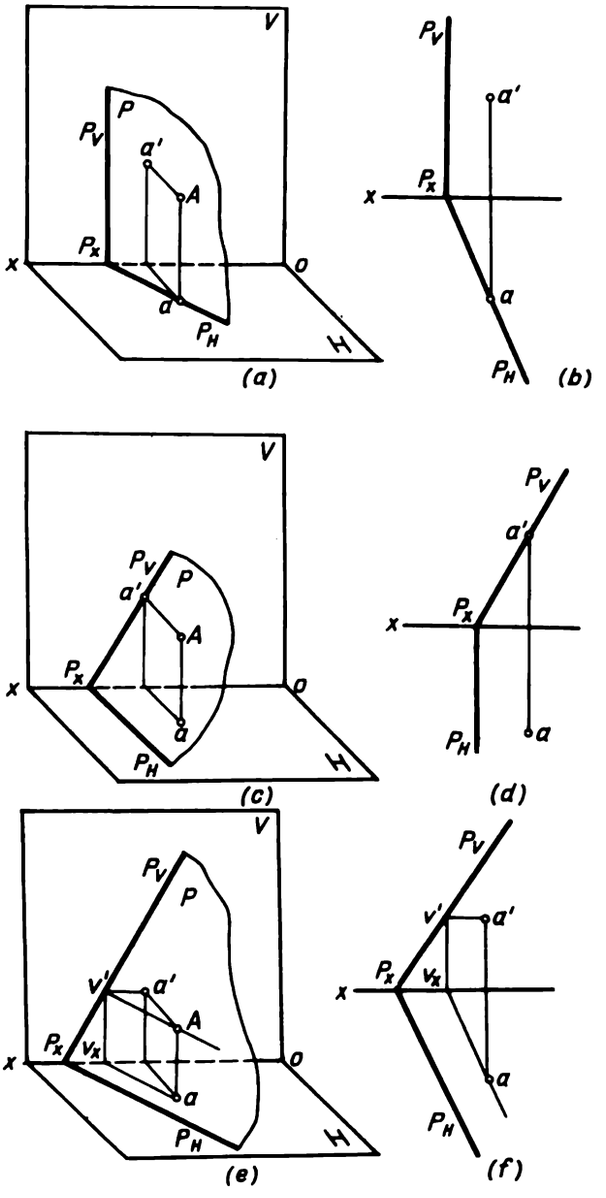


Fig. 144

and *b*) is situated on the horizontal projection of the horizontal trace of the plane.

Given the vertical projection a' of a point A located on a horizontal projecting plane P, the horizontal projection of this point can be determined without drawing an auxiliary line, simply by directly projecting a' on the trace P_H. If a point is located on a *vertical projecting plane P* (see Fig. 144*c* and *d*), its vertical projection will be found on the vertical trace of the plane P.

Point A on an oblique plane P is determined with the aid of an auxiliary straight line situated on the same plane. Such a line may be drawn in any direction, but to make all the constructions simpler, it is good practice to draw a *horizontal* or a *vertical line*. Then mark on the trace of the plane a point, the trace of the auxiliary line, and draw the projections of the line by using this trace.

For example, to find a point A on the plane P shown in Fig. 144*e* and *f*, mark a point v' (the vertical projection of the vertical trace of the auxiliary horizontal line) on the trace P_V. The horizontal projection of this trace, v_x, will be located on the axis ox. Draw the vertical projection of this horizontal line through v' and parallel to the axis ox, and its horizontal projection through v_x parallel to the trace P_H. Now mark the vertical projection a' of the required point on the vertical projection of the horizontal line, and then determine the horizontal projection a of the point A by drawing a vertical line $a'a$.

4. PROJECTIONS OF PLANE FIGURES

Having learned the methods of constructing the projections of straight lines and points located on a plane, we can now proceed with projections of any figure contained in this plane, for instance, a rectangle, triangle, circle and so on.

As is known, each plane figure is bounded by straight or curved lines which can be constructed from given points. The projections of a figure formed by straight lines — triangles and polygons — are usually constructed from given vertices. Then the like projections of the vertices are joined by straight lines to obtain the required projections of the figure. Projections of a circle or any other curvilinear figure are constructed with the aid of a series of evenly spaced points of the contour. The like projections of the points are then joined by a smooth line using a French curve.

Projections of a plane figure are constructed in different ways depending on the position of the figure relative to the planes of projection H and V. The simplest to construct are projections of a figure placed parallel to the plane H or V. The constructions become more complicated when a figure is located on a projecting plane or on an oblique plane.

Here are two examples.

1. If the plane of the triangle ABC (Fig. 145*a*) is parallel to the plane H, then it will be projected on this plane true size, while its vertical projection will be a straight line parallel to the axis ox. This is orthographically represented in

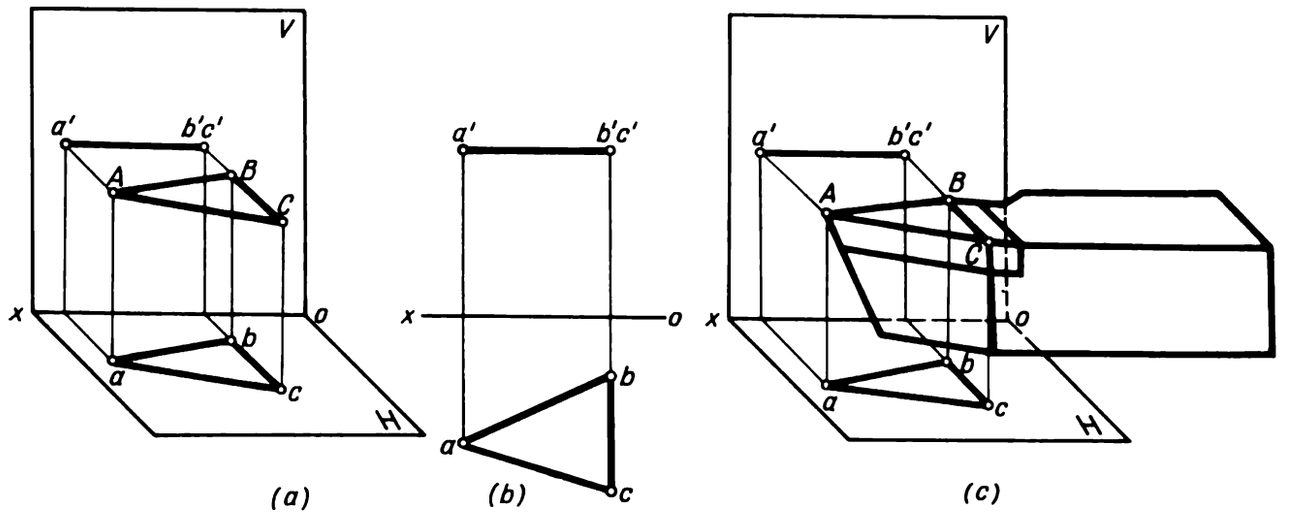


Fig. 145

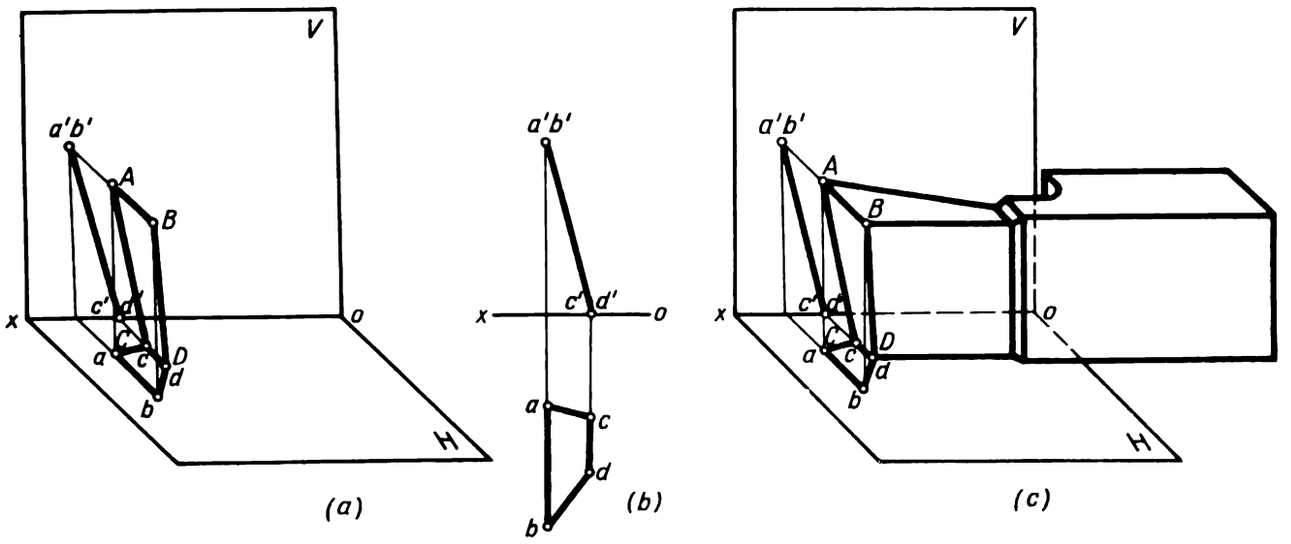


Fig. 146

Fig. 145*b*. A practical application is shown in Fig. 145*c* illustrating the face *ABC* of a thread tool.

2. The plane of the trapezoid *ABDC* (Fig. 146*a*) is a vertical projecting plane. The vertical projection of the trapezoid will be a straight line. On the horizontal plane of projection the figure is projected as a distorted trapezoid (see also Fig. 146*b*). A practical application is given in Fig. 146*c*.

Examining planes parallel to one of the planes of projection, i.e., horizontal, vertical and profile planes, we may state the following.

One of the projections of any figure lying on such a plane is the true shape of this figure, the other two coinciding with the traces of the plane.

Examining projecting planes we may state that one of the projections of any point, straight or curved line, as well as plane figure located on a projecting plane, coincides with the trace of this plane. For example, the vertical projection of the circle (Fig. 147*a*) contained in the

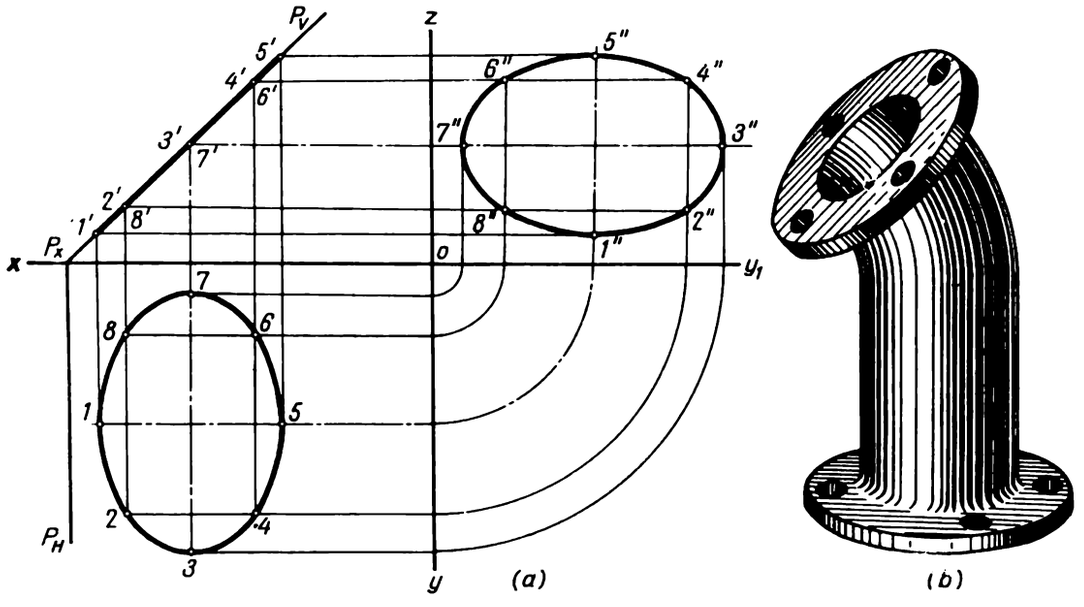


Fig. 147

vertical projecting plane P coincides with the vertical trace P_V of the plane P. Its horizontal and profile projections are distorted into ellipses with the major axes equal to the projections of the circle's diameter *3-7* and *3''-7''*, and minor axes equal to the projections of the circle's diameter *1-5* and *1''-5''* which are perpendicular to diameter projections *3-7* and *3''-7''*, respectively.

Illustrated in Fig. 147*b* is an example from engineering practice with the circles situated in a projecting plane. The horizontal projection of the contour of the lower flange will show the true shape and size of the circle, while the horizontal projection of the outline of the upper flange is an ellipse.

5. RELATIVE POSITIONS OF TWO PLANES

Two planes in space may be either mutually parallel, coinciding in a special case, or intersecting. Mutually perpendicular planes are a special case of intersecting planes.

We know from descriptive geometry that two parallel planes intersect a third along parallel lines. Thus like traces of parallel planes are parallel.

To judge about the parallelism of profile projecting planes it is necessary to construct their profile traces, since the parallelism of their vertical and horizontal traces on a drawing is not sufficient. If the profile traces are also parallel, then the planes are parallel; otherwise they are not parallel (see Fig. 148).

The like traces of two intersecting planes P and Q intersect (Fig. 149*a* and *b*). The points of intersection of the traces belong to both planes, i.e., to the line of their intersection. Since these points are situated on the projection planes, they are the traces of the line along which the planes intersect.

A simple rule for finding the line of intersection of two planes P and Q follows from the above argument: determine the points of intersection of the like traces of the planes (that is, P_V and Q_V, and P_H and Q_H) and consider them as the traces of the required line of intersection of the planes P and Q. The projections of the required line are constructed by drawing a straight line through the like projections of its traces (Fig. 149*b*).

Thus, to determine the projections of the line of intersection of the two planes P and Q specified by their traces P_V, P_X, P_H and Q_V, Q_X, Q_H, it is necessary to mark the points of intersection of the like traces of the planes, i.e., the points v' and h (Fig. 149*b*). The point v' is the vertical projection of the vertical trace of the required line of intersection of the planes P and Q, the point h being the horizontal projection of the horizontal trace of the same line. The second projections of these traces, points v and h', are found by dropping perpendiculars from v' and h on the axis ox. By joining the like projections of the traces, i.e., v' and h', v and h, with straight lines, we obtain the projections of the required line of intersection of the planes P and Q.

The relative positions of a straight line and a

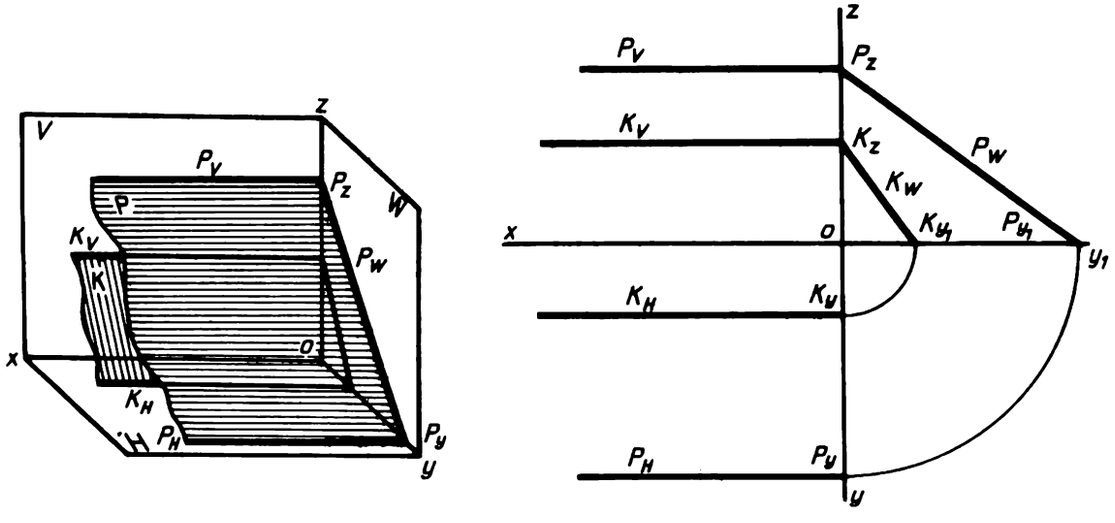


Fig. 148

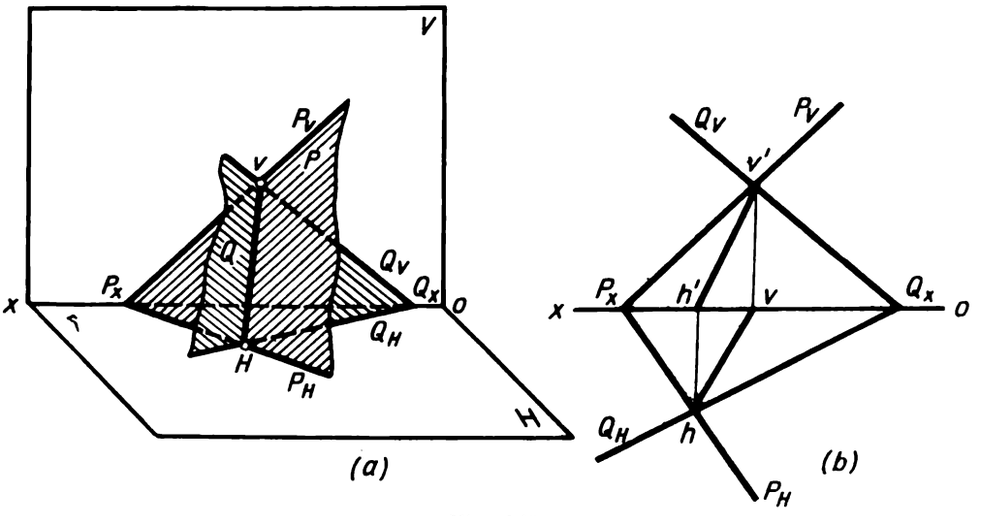


Fig. 149

plane. There are three possible variants of the relative positions of line and plane:

(1) the line belongs to the plane,

(2) the line is parallel to the plane, and

(3) the line intersects the plane.

When deciding on the parallelism of a line and a plane it is necessary to invoke the familiar proposition of solid geometry: a line is parallel to a plane if it is parallel to one of the lines lying in that plane. And vice versa: if a line is parallel to a plane, then it must be parallel to one of the lines lying on the given plane.

Therefore, if it is required to draw, through a given point A, a line parallel to a plane P (Fig. 150), first draw any line on this plane and then through the given point A draw the required line parallel to the arbitrary one. In doing so bear in mind that like projections of parallel lines must be parallel.

In the present example a horizontal line BV is arbitrarily drawn on the plane P. To draw this line, proceed as follows:

(a) mark any point (v') on the trace P_V and consider it the vertical projection of the vertical trace of the required line;

(b) through the point v' draw a straight line parallel to ox to obtain the vertical projection of the required line;

(c) drop a perpendicular from v' to ox to obtain the horizontal projection of the vertical trace of the required line (point v);

(d) through v draw a line vb parallel to P_H to obtain the horizontal projection of the required line;

(e) finally, through the given projections a' and a of the point A draw lines $a'v'$ and av parallel to $v'b'$ and vb, respectively. These will be the projections of the required straight line AV parallel to the plane P. Through the given point A a second horizontal line AV is drawn which is parallel to the first one, BV. The like projections of these horizontal lines are parallel.

6. A LINE CUTTING A PLANE

The point of intersection of a line and a plane P is determined in the following way.

Given: plane P defined by traces P_V and P_H (Fig. 151*a*).

Through the straight line AB pass any auxiliary plane Q. For the sake of simplicity a pro-

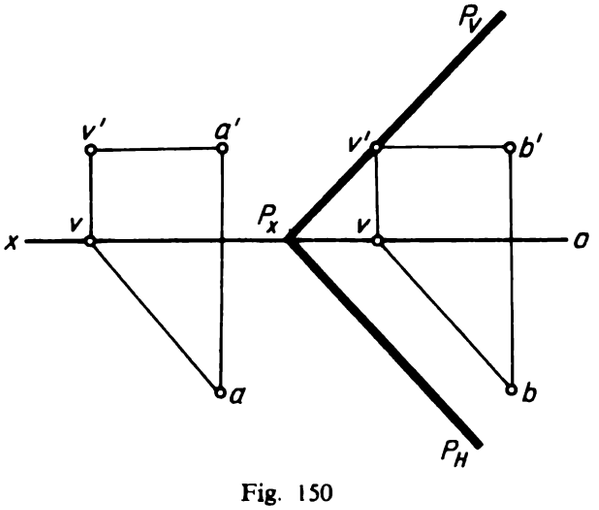


Fig. 150

jecting plane is usually taken. In this case it is the auxiliary horizontal projecting plane Q. Through the horizontal projection ab of AB draw the horizontal trace Q_H and extend it to intersect ox at point Q_x. At this point erect a perpendicular Q_xQ_V to ox which will be the vertical trace of the auxiliary plane Q.

This plane will intersect the given plane P along the line VH. Construct the projections of this line, bearing in mind that its traces lie at points of intersection of the traces of the given plane P and auxiliary plane Q. Mark the points of intersection of the traces P_V and Q_V (point v'), and the traces P_H and Q_H (point h) and drop perpendiculars from the points v' and h to ox. The points of intersection v and h' are the second projections of these points (i.e., traces). Join v' and h' to obtain the vertical projection of the line along which the planes intersect. The horizontal projection of this line will be the straight line joining v and h.

The point of intersection M of the given line, AB, and the determined one, VH, is the required point of intersection of the line AB and the plane P. The vertical projection of this point is located at the point of intersection of $a'b'$ and $v'h'$. The horizontal projection m of the point M is found by vertically projecting the point m' on ab.

In exercises on determining the point of intersection of a given straight line with a plane (say, a triangle) the following method is recommended (Fig. 151*b*).

Given: line MN.

Pass an auxiliary vertical projecting plane P through MN. To this end, through points m' and n' draw the vertical trace of P, extending it to intersect the axis ox. At the point of intersection of P_V and ox erect a perpendicular P_H to ox which will be the horizontal trace of the plane P.

Then find the line ED of intersection of the plane P and the plane of the given triangle ABC. It is obvious that the vertical projection $e'd'$ of ED coincides with the vertical trace of the plane, P_V. The horizontal projection ed is found by vertically projecting the points of intersection of the line $e'd'$ and sides $a'b'$ and $a'c'$ of the triangle $a'b'c'$. Join e and d by a straight line. Now find the horizontal projection k of the required point which is the point of intersection of the horizontal projection ed of the line ED and the horizontal projection mn of the line MN. The vertical projection k' is constructed by vertically projecting the point k on the line $e'd'$.

Assuming the plane ABC to be opaque, it is necessary, proceeding from the drawing, to imagine the position of this plane in space relative to the straight line MN and to separate the visible part of the line from the hidden part.

This problem is solved by the *method of competing points.*

Consider two skew lines MN and AB (Fig. 151*b*) of a certain thickness (like rods). On an orthographic drawing these lines will have two

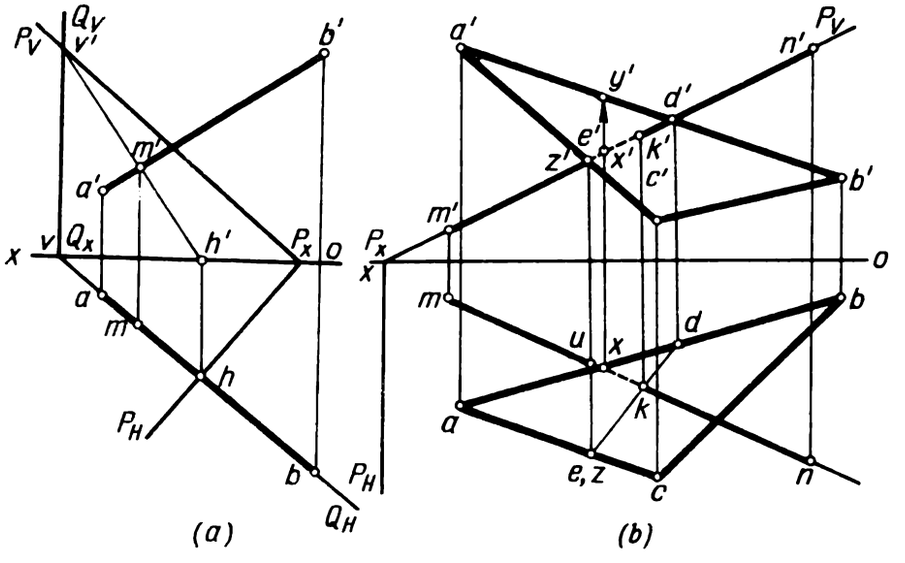


Fig. 151

pairs of like projections intersecting at competing points.

Since the lines themselves do not intersect, their competing points are located on their unlike projections (vertical and horizontal) without any orthographic correlation.

The horizontal projections *ab* and *mn* intersect at one point *x*, whereas its vertical projection may be either of the two competing points *x'* and *y'*. The point *y'* is situated higher than *x'* relative to the *H* plane, hence, the line *ab* will cover the line *mn*.

The vertical projections of *MN* and *AC* intersect at one point *z'* coinciding with the point *e'*, while its horizontal projection may be either of the two competing points *u* and *z*. Since the point *z* is farther from the *V* plane than *u*, the line *a'c'* will cover the line *m'n'* on the vertical projection.

The two intersecting lines *AB* and *AC* completely specify the plane of the triangle *ABC* which will cover a portion of the line *MN* between the point of intersection *K* and *M*; the parts of the projections of the line limited by points *k'* and *z'*, and *k* and *u* will be hidden.

7. INTERSECTING PLANES

Lines of intersection of two planes may be constructed similarly to the above considered method.

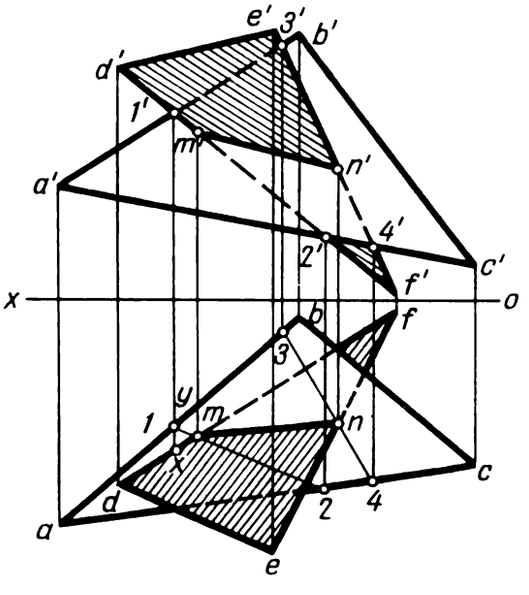


Fig. 152

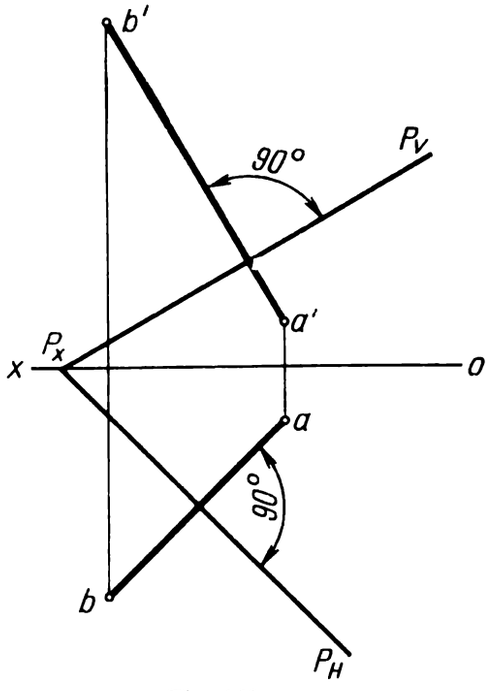


Fig. 153

Fig. 152 illustrates the construction of the line of intersection of two planes specified by opaque triangles *ABC* and *DEF*. The line *MN* is constructed from the points of intersection of the triangle's sides *DF* and *EF* with the plane of the triangle *ABC*.

To find point *M*, through *DF* pass a vertical projecting plane (the traces of this plane are not shown in the drawing), which intersects the triangle *ABC* along line *1-2*. Project points *1'* and *2'* thus obtained onto the horizontal projection of the triangle. The horizontal projection of the required point *M*, the point of intersection of *DF* and *ABC*, is obtained as the point of intersection of the horizontal projections *df* and *1-2;* then the vertical projection *m'* is constructed.

The point *N* of intersection of the line *EF* and the triangle *ABC* is found in the same manner. Since the intersecting planes are opaque, it is necessary to determine the invisible areas of both planes and to show them with dash lines. The visibility of lines is determined using the method of *competing points.*

For example, part of the line *DF* is situated nearer to the viewer than the line *AB*, i.e., part of *AB* is hidden. This is clearly seen from a comparison of the competing points *x* and *y* lying on these lines. The horizontal projection of point *x* is farther from the plane *V*, hence,

the line *DF* is nearer to the viewer and part of it *(DM)* will be visible.

The same consideration is valid for the skew lines *EF* and *AB*.

If a *straight line AB is perpendicular to a plane P*, then the projections of this line are perpendicular to like traces of the plane, i.e., the vertical projection *a'b'* of a line perpendicular to the plane *P* is perpendicular to the vertical trace P_V, and the horizontal projection *ab* of the line is perpendicular to the horizontal trace P_H (Fig. 153). This theorem is proved in descriptive geometry. The converse theorem also holds: if the projections of a line are perpendicular to like traces of a plane, then this line is perpendicular to the plane.

Questions

1. Name the methods of specifying a plane on a drawing.
2. How many traces has an oblique plane in the three-plane system of projection? Name the traces.
3. Name the three types of projecting planes.
4. Where are traces of a line lying on the plane *H* located on a drawing?
5. Define the positions of the projections of a horizontal and a vertical line lying on a given plane.
6. How is a straight line lying on a plane specified by its traces and on a plane specified by two parallel lines determined in a drawing?
7. What is the necessary condition for a point to be located on a given plane?
8. How is a figure constructed on a plane specified by its traces?
9. What is the criterion of parallelism for two planes in a three-view drawing?
10. How can a plane be passed through a given point parallel to a given plane?
11. How can a straight line be drawn through a given point parallel to a given plane?
12. Give the sequence to be followed in constructing the point of intersection of a line and an oblique plane.
13. How is the visibility of lines determined on an orthographic drawing using the method of competing points?
14. How can the line of intersection of two oblique planes specified by their traces be determined?
15. How can the line of intersection of two oblique planes specified by intersecting lines be determined?
16. What is the necessary condition for perpendicularity of a straight line to a plane?

Exercise 18

Designate and name the traces of the planes in Fig. 154*a*.

Exercise 19

Construct the projections of point *A*, situated on plane *P* (Fig. 154*b*), in space and in a drawing.

Exercise 20

Construct the projections of points *A* and *B*, located on plane *P* (Fig. 154*c*), in space.

Exercise 21

Construct the projections of straight line *AB*, situated on plane *P* (Fig. 154*d*), in space and in a drawing.

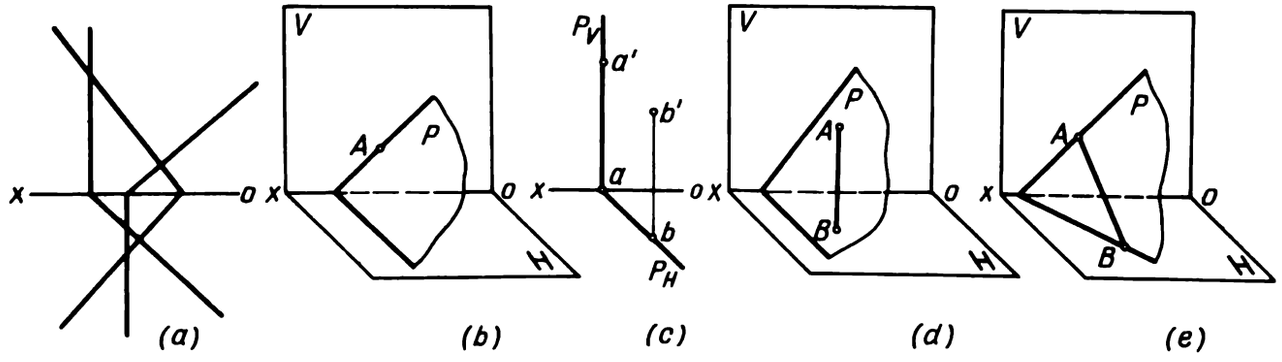


Fig. 154

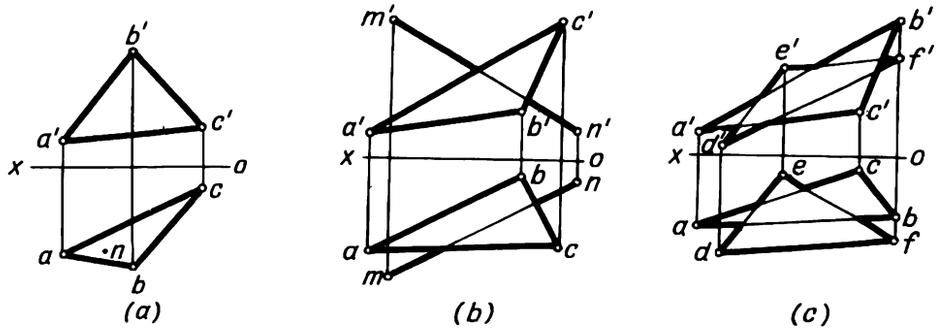


Fig. 155

Exercise 22

Construct the projections of straight line *AB*, situated on the plane *P* (Fig. 154*e*), in space and in a drawing.

Exercise 23

Construct three projections of a triangle in a drawing, given its coordinates tabulated below.

Task No.	*x*			*y*			*z*		
	A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
1	50	15	15	20	20	50	10	10	10
2	42	5	20	0	30	25	42	12	38

Exercise 24

Construct three projections of point *N*, contained in the plane of the triangle *ABC* (Fig. 155*a*), in a drawing.

Exercise 25

Construct three projections of the point of intersection of line *MN* with the plane of the triangle *ABC* (Fig. 155*b*), in a drawing.

Exercise 26

Construct three projections of the line of intersection of two triangles, *ABC* and *DEF* (Fig. 155*c*), in a drawing.

CHAPTER 5

METHODS OF REVOLUTION, COINCIDENCE AND REPLACEMENT OF PLANES OF PROJECTION

1. DETERMINING THE TRUE IMAGE OF PLANE FIGURES

In orthographically projecting straight or plane curved lines, as well as figures (triangle, circle, etc.) on three planes of projection, *H*, *V*, and *W*, we noticed the following.

The true length of lines and true geometrical shapes of figures are obtained only on the plane of projection parallel to which these lines and figures are situated. The line *AB* in Fig. 156 which is parallel to the plane *V* (that is a vertical line) is projected in true length on the plane *V*, or, in other words: the length of the vertical projection *a'b'* of the vertical line *AB* is equal to the true length of this line.

One more example. If the plane of the triangle *ABC* is parallel to the vertical plane of projection, then it is projected on this plane without distortion, i.e., in true size.

In engineering drawing it is sometimes necessary (with the orthographic projections of a certain machine part given) to determine the true image of an element of the part which is not parallel to any of the planes of projection. To this end, use is made of special methods of construction on orthographic drawings: rotation, coincidence (which is a particular case of the previous method), and replacement of planes of projection.

Many other problems in projection drawing are solved by applying these methods. The following data can be determined:

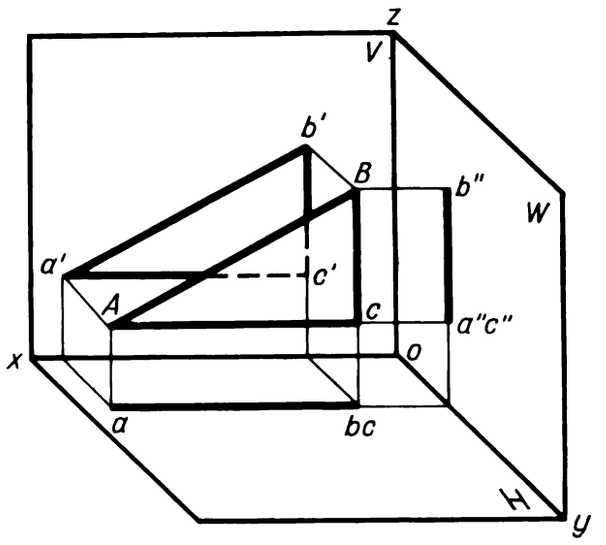


Fig. 156

(a) the true length of a straight line inclined to a projection plane; for example, the true length of the edge *AB* (Fig. 157) of the hood of a gas furnace for heat treatment of tools. The true length of the edge is required in constructing the development of the side surface of the pyramid-shaped hood. The developed surface of the pyramid is required for cutting the hood out of a steel sheet;

(b) the true dimensions and image (shape) of an oblique plane figure;

(c) the angles formed by a straight line of general position or an oblique plane and the planes of projection;

(d) the angle formed by lines or planes;

(e) the distance between two points;

(f) the distance between a point and a line;

(g) the distance between parallel lines;

(h) the distance between skew lines;

(i) the distance between a point and a plane;

(j) the distance between a plane and a line parallel to it;

(k) the distance between parallel planes;

(l) the angle formed by a line and a plane; and some other data.

2. THE METHOD OF REVOLUTION

In this method a given point, line, plane figure or solid, placed in front of the planes of projection *H*, *V*, and *W*, is *revolved about an axis perpendicular to one of the projection planes* till the required position relative to a certain plane of projection is attained.

Consider the revolution of the simplest geometrical element, point *A* (Fig. 158*a*). The axis of revolution *I* is perpendicular to the plane *H*. Revolving about the axis *I*, point *A* describes a circle, whose plane is perpendicular to the axis of revolution. The point of intersection of this plane and the axis of revolution is called the *centre of revolution.*

Since the circle of revolution of point *A* is parallel to the plane *H*, the horizontal projection of the circle is undistorted (true size), the vertical projection being a straight line parallel to the axis *ox* and equal in length to the circle's diameter (Fig. 158*b*).

Thus, when point *A* is revolving about an axis perpendicular to a plane of projection, the projection of the point on this plane will describe a circle. The other projection of point *A* will be in motion along a straight line parallel to the axis of projection.

Let us revolve the given point *A* about an axis *I* perpendicular to the plane *V*, through a

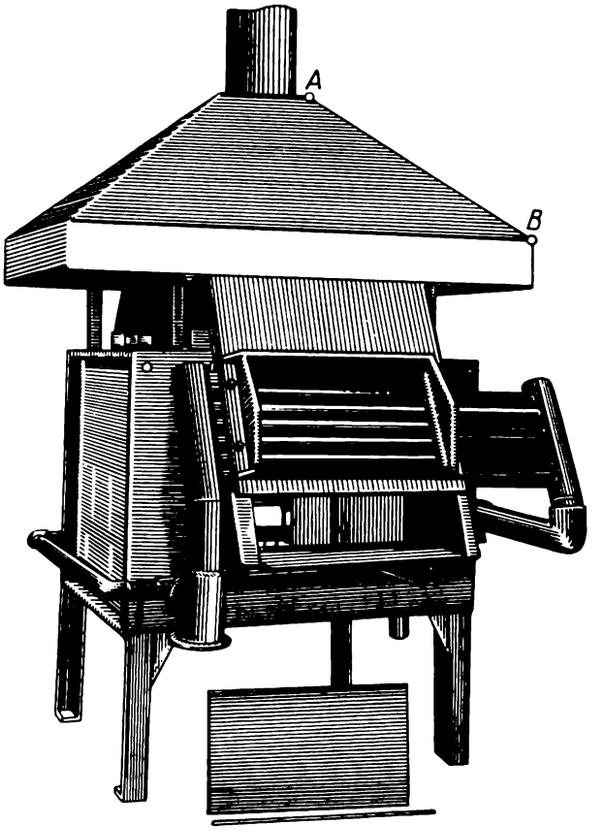


Fig. 157

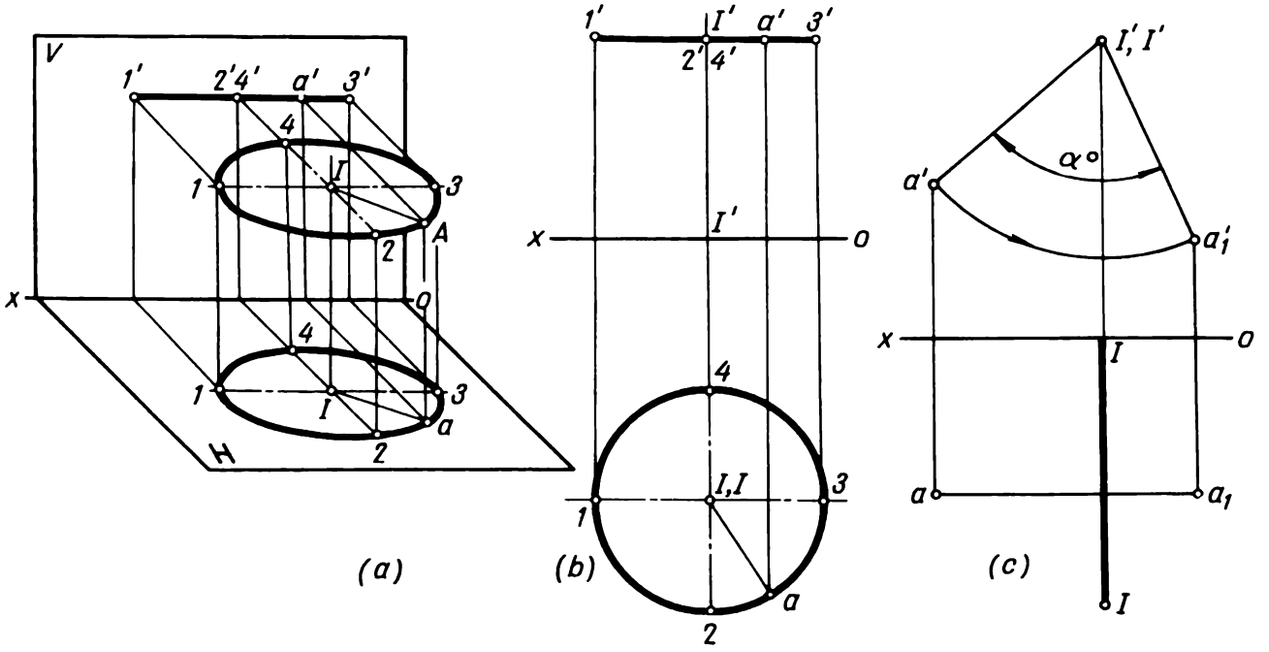


Fig. 158

given angle α (Fig. 158*c*). To do so, the following constructions should be made on the drawing.

Join the point $I'I'$ (the vertical projection of the axis of revolution) to the point a' (the vertical projection of point A) with a straight line $I'a'$ to obtain the true length of the radius of the circle of revolution. Describe an arc of this radius with the point I' as a centre.

On the V plane construct the angle α one side of which is the line $I'a'$. The point of intersection a'_1 of the circle of revolution and the other side of the angle α will be the new vertical projection of point A after revolution. The new horizontal projection of A is found by projecting the point a'_1 on a line drawn through a and parallel to the axis ox.

Revolution of a line about an axis perpendicular to a projection plane may be considered as revolution of two points of this line (usually the two end points).

The constructions are simplified to a great extent if the axis of revolution is drawn through any end point of the line to be revolved. Thus

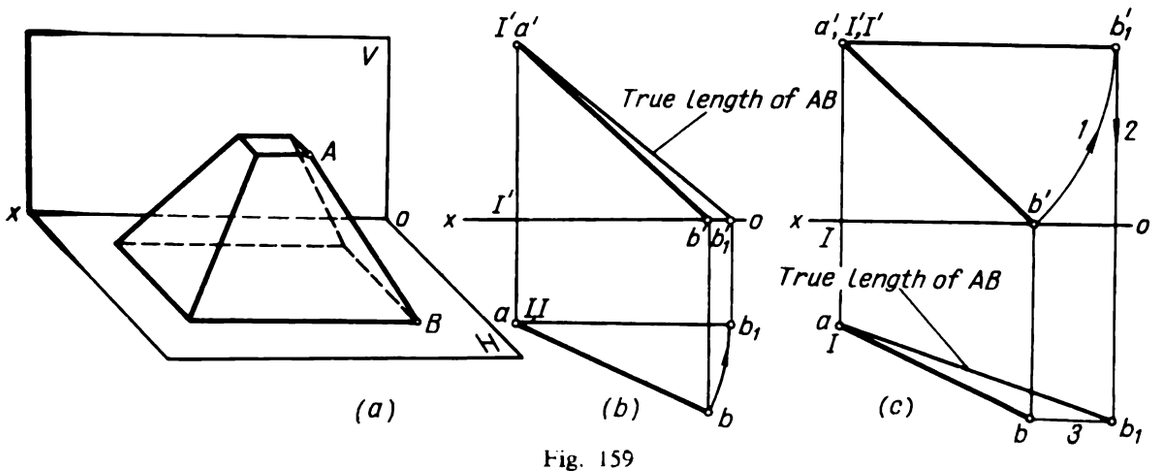


Fig. 159

it is sufficient to revolve only one end point on the line, since the other end point located on the axis of revolution remains fixed.

Let us now consider an example from engineering practice where it is necessary to determine the true length of a line of general position using the method of revolution. We refer once again to the edge *AB* of the pyramid-shaped hood of the gas furnace in Fig. 157. The construction of the hood is shown in Fig. 159*a*.

Through the end of *AB* (point *A*) draw the axis of revolution *I-I* perpendicular to the plane *H* (Fig. 159*b*). The second end (point *B*) will revolve about this axis. To obtain the true length of *AB*, revolve it about the axis until it occupies a position parallel to the plane *V*, at which *AB* will be projected true length on the plane *V*.

As a result of this revolution the horizontal projection of *AB* becomes parallel to the axis *ox;* that is why it is convenient to begin the necessary constructions on the plane *H*. From point *a* as a centre and with a radius equal to *ab* describe an arc to intersect the line drawn through the point *a* parallel to the axis *ox*. The point of intersection b_1 is thus the new horizontal projection of point *B*. The vertical projection b'_1 is constructed by projecting the point b_1 on the straight line drawn through *b'* parallel to *ox* (in the present case this line coincides with the axis *ox*). Join b'_1 and *a'* by a straight line to obtain the true length of *AB*.

This problem can also be solved by revolving *AB* about an axis which is perpendicular to the plane *V*. This is done in the following way. Draw the axis of revolution *I-I* through the end point *A* (Fig. 159*c*). From *a'* as a centre and with a radius equal to *a'b'* describe an arc to intersect the line drawn through *a'* parallel to *ox*. The point of intersection b'_1 is the newly obtained vertical projection of the end *B*. The new horizontal projection b_1 is obtained by drawing from *b* a line parallel to *ox* and projecting on it the point b'_1. Join b_1 and *a* by a straight line to obtain the true length of *AB*.

The same method (of revolving points) can be applied in revolving any plane figure. If a plane figure is not perpendicular to any plane of projection, then it is impossible to determine its true size by one revolution of the figure about one axis. In this case we must go through two consecutive revolutions about two axes perpendicular to two planes of projection.

The first revolution brings the figure to a position perpendicular to either of the planes of projection, the second to a position in which the figure becomes parallel to the other plane of projection and is projected on it in true size.

Figure 160*a* presents a practical application of this method in mechanical engineering. Shown in the figure is a supporting roller for a belt conveyor. The plane figure to be determined in

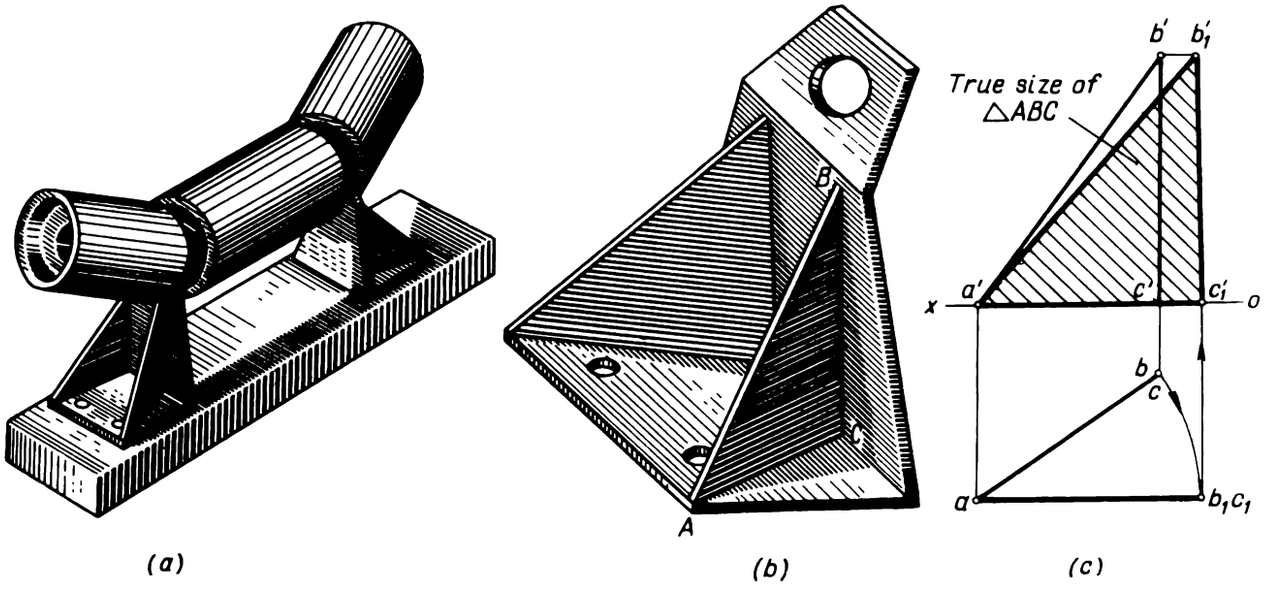


Fig. 160

full size is the rib *ABC* having the shape of a right triangle (Fig. 160*b*).

As is seen from the figure, this triangle lies in a horizontal projecting plane (i.e., in a plane perpendicular to the plane *H*). This fact permits determination of the true size of the triangle on the plane *V* by revolving its plane about a vertical axis until it becomes parallel to the plane *V*.

In the orthographic drawing (Fig. 160*c*) the axis of revolution aa_1 is perpendicular to the plane *H* and is drawn through the triangle's vertex *A*. The other two vertices *B* and *C* are revolved simultaneously. As a result of the revolution the horizontal projection of the triangle, ab_1c_1, becomes parallel to *ox*. The vertical projections of *B* and *C* after revolution are found by projecting points c_1 and b_1 on the plane *V*. Join the points a', b_1', c_1' on the plane *V* by straight lines to obtain the true size of the triangle *ABC*.

The method of revolution can also be applied to determine the true shape of a curved figure on a drawing. An example from mechanical engineering, a mixer, is presented in Fig. 161. Shown in Fig. 162 is a pictorial view of a mixer blade having curved outlines. Since the blade is at an angle to the axis of the shaft, and the shaft hole axis is parallel to the axis *oy* in the drawing (Fig. 163), the vertical and profile projections present distorted images of the blade.

To determine the true shape of the blade in the drawing using the method of revolution, let

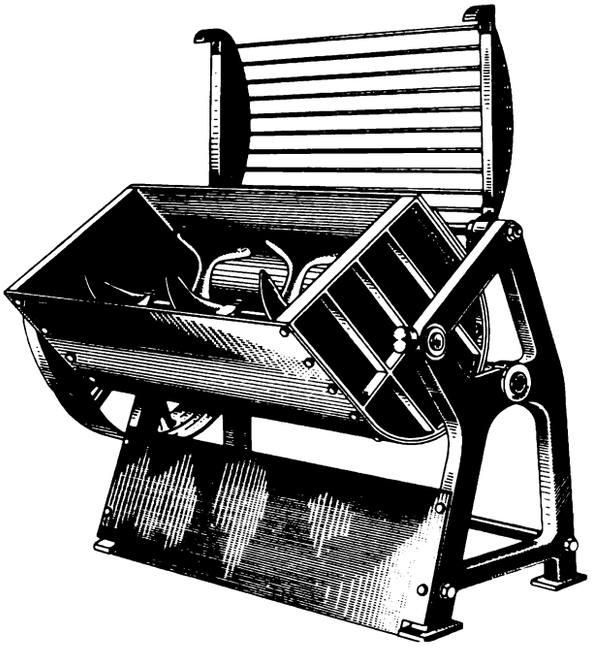


Fig. 161

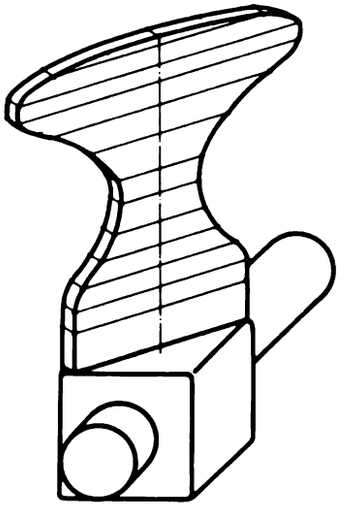


Fig. 162

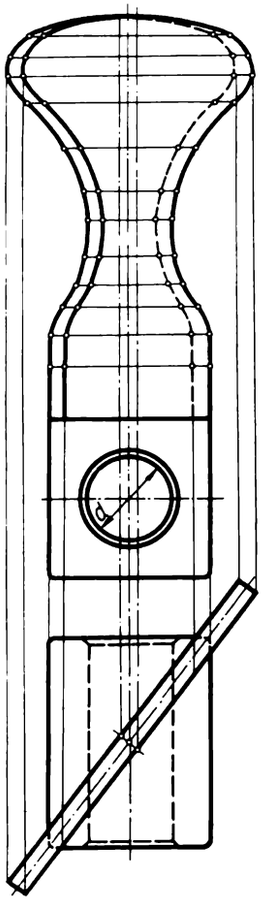


Fig. 163

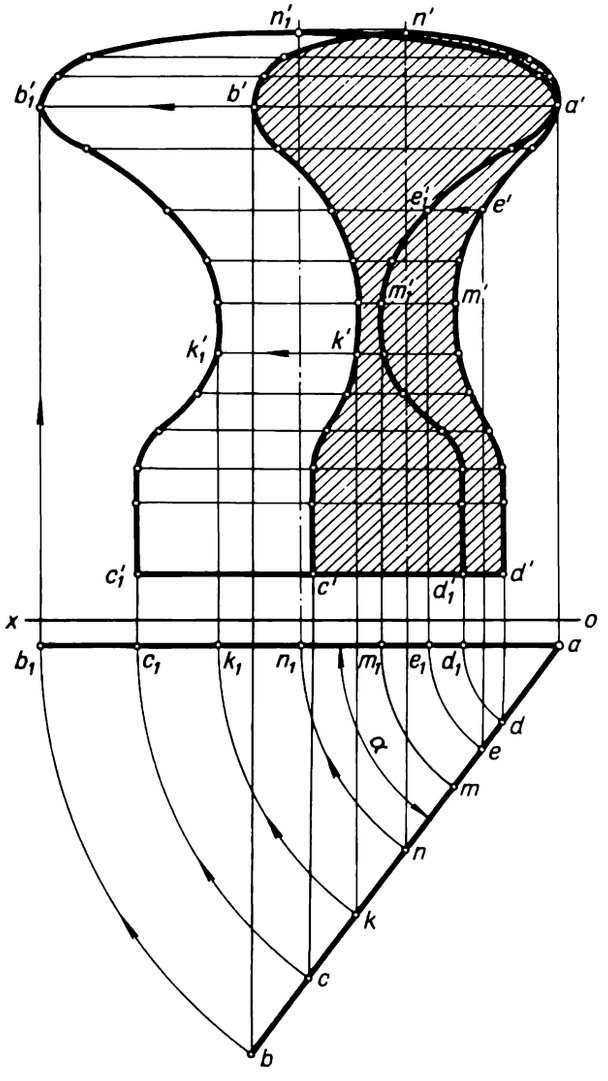


Fig. 164

us take a series of arbitrary points on the vertical projection of the blade — a', e', m', d', c', k', b', n' (Fig. 164). Now, by projecting these points on the horizontal projection of the blade which is a straight line ab making an angle α with ox, find their horizontal projections a, d, e, m, n, k, c, b. Then draw a vertical axis of revolution through point a' and revolve the line ab through the angle α about the centre of revolution (point a) until it is parallel to the plane V. Finally, find the new vertical projection of the blade which will be its true image.

To construct the new vertical projection of a point on the blade outline (say, point e'), draw an arc, from a as a centre and with a radius equal to ae, to intersect the new horizontal projection of the outline ab_1 (which is parallel to the axis ox) at e_1.

This construction was considered in detail in the foregoing text, where the method of revolving a point about an axis perpendicular to a projection plane was explained.

The point e_1 is then projected on the straight line drawn from e' parallel to the axis ox. The point e_1' of intersection will belong to the newly constructed vertical projection of the blade. And finally, draw a smooth curved line through the points thus obtained which will be the true image of the mixer blade.

3. THE COINCIDENCE METHOD

Coincidence is a special case of the method of revolution of a plane when one of its traces serves as the axis of revolution (see Fig. 165*a* and *b*).

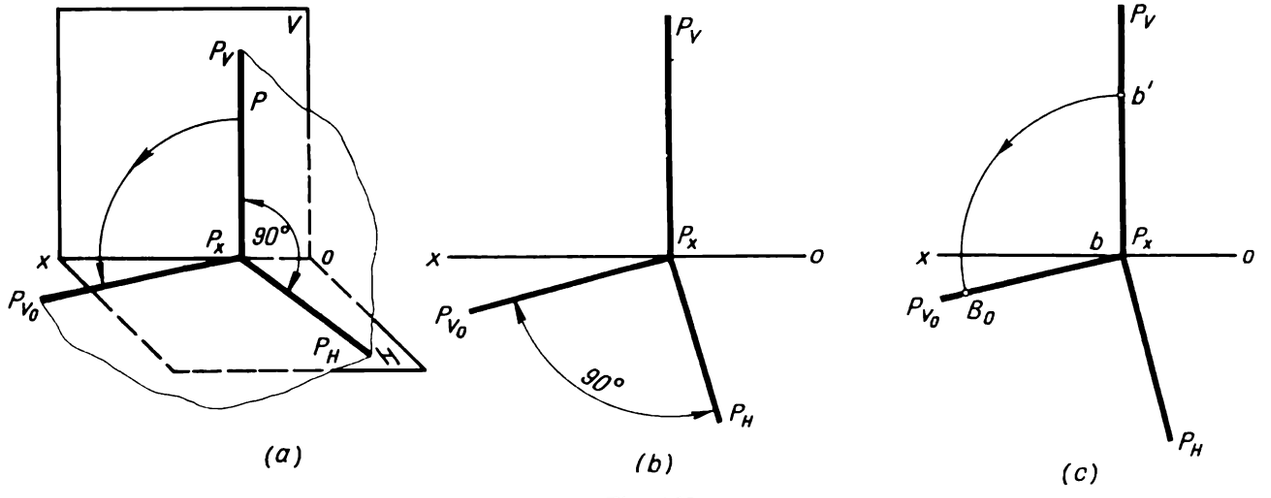


Fig. 165

As a result of such revolution, the given plane P is brought into coincidence with one of the projection planes. On the latter plane we get a true size representation of the figures contained in the plane P. This method does not contain any fundamentally new features. We therefore confine ourselves to the description of a few of its peculiarities.

To bring a point, a line or a plane figure into coincidence with one of the projection planes, first pass an auxiliary plane P through this point, line or plane figure. Then, by revolving the plane P about its trace P_H or P_V, bring it into coincidence with the corresponding plane of projection.

It is convenient and simple to pass (if possible) through the given point (line or plane figure) a projecting plane, for instance, a horizontal projecting plane. No matter what the original position of a horizontal projecting plane P, its traces will be at a right angle after coincidence (Fig. 165*a* and *b*). In bringing the horizontal projecting plane P to coincidence with the plane H by revolving it about the horizontal trace P_H we see that the vertical trace P_{V_0}, after being brought to coincidence, is at a right angle to the fixed horizontal trace P_H (Fig. 165*b*).

If a point contained in the horizontal projecting plane P is taken on the horizontal trace P_H which is the axis of revolution and, hence, fixed, then, after the plane P is brought to coincidence with the plane H, the point retains its former position.

If we take now a point B in the same plane on the vertical trace P_V (Fig. 165*c*), then point B_0 brought to coincidence will lie on the trace P_{V_0}, the distance P_xB_0 being equal to P_xb'.

Since a straight line can be specified by two points, it will suffice to bring these points, and hence the line, to coincidence with the plane H by passing a plane P (say, a vertical projecting plane) through the straight line AB (Fig. 166*a*). Then the plane H will show the true length of this line.

The problem of determining the true length of a straight line AB by the coincidence method is solved in the following way. Through the end point B situated on the plane H draw (perpendicularly to the axis ox) the horizontal trace P_H of the vertical projecting plane P. Draw the trace P_{V_0} through points a' and b'. Bring plane P to coincidence with the plane H; now the trace P_{V_0}, coincides with the axis ox. From P_x as a centre and with a radius equal to P_xa' describe an arc to intersect the trace P_{V_0}. Drop a perpendicular from point a to the trace P_H and extend it to intersect the straight line drawn from the point P_{V_0} parallel to the trace P_H at point A_0 which will be the new position of point A. Join A_0 and b by a straight line which will be the true length of the line AB.

Fig. 166*b* illustrates the use of the coincidence method for determining the true size of a plane figure (triangle ABC). Just as in the similar problem solved by the method of revolution (see

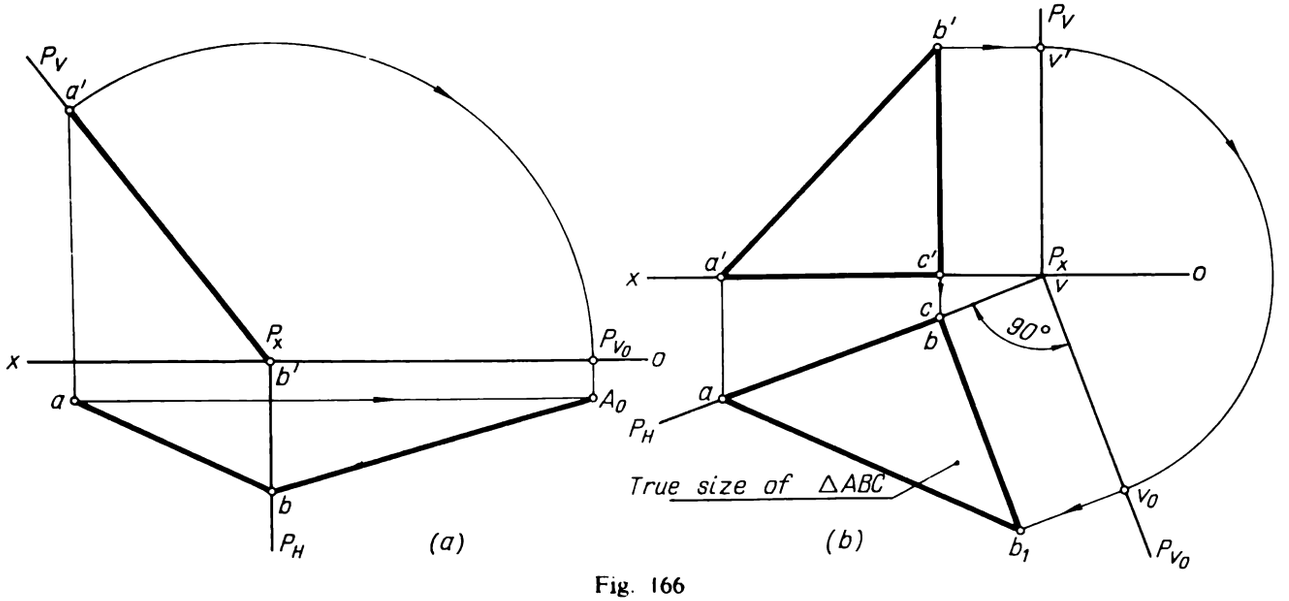


Fig. 166

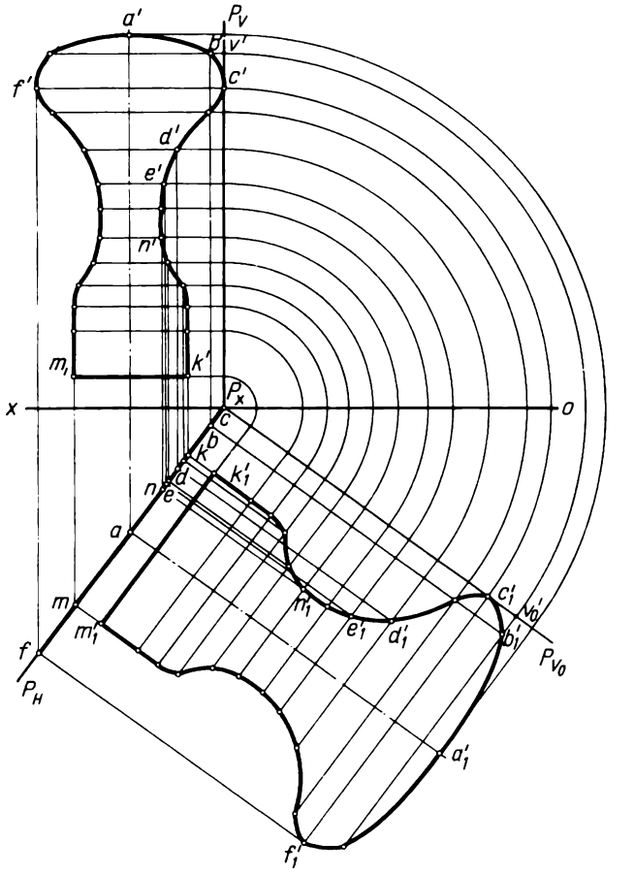


Fig. 167

Fig. 160*c*), we shall consider the case when the plane of the given triangle is a horizontal projecting plane.

First draw the traces P_V and P_H of the plane containing the triangle *ABC*. Since the side *AC* of the triangle is situated on the plane *H*, its projection *ac* coincides with the trace P_H, while the trace P_V is perpendicular to the axis *ox*.

Then bring the vertical trace P_V to coincidence with the plane *H;* it will be at a right angle to the horizontal trace P_H.

To construct the transformed position of point *B* draw a straight line from point *b'* parallel to the axis *ox* to intersect the trace P_V at point *v'*. From *v* as a centre and with a radius equal to $P_x v'$ describe an arc to intersect P_{V_0} at point v_0 which is the transformed position of point *v*. From point v_0 draw a straight line parallel to the trace P_H. Now find the transformed position of point *B* by erecting a perpendicular to P_H at point *b* to intersect the line drawn from v_0 parallel to P_H; b_1 is the required point.

The true size of a curved figure (for example, the mixer blade shown in Fig. 162) is found in the same manner, the only difference being that a series of arbitrarily taken points on the curved outline are brought to coincidence.

The solution of this problem is given in Fig. 167. Drawn through the figure is a horizontal projecting plane specified by the traces P_V and P_H. Then a series of random points are taken on the blade outline (*A*, *B*, *C*, *D*, etc.) and horizontal lines are drawn through them. The plane *P* together with these horizontal lines is brought to coincidence with the plane *H*. The transformed positions of the points are found on the corresponding transformed horizontal lines. The points a'_1, b'_1, c'_1, d'_1, etc. thus obtained are joined by a smooth curved line. For example, to bring point *B* to coincidence with the plane *H* a horizontal line is drawn through this point. The vertical projection of this horizontal line is parallel to the axis *ox*, while its horizontal projection coincides with the horizontal trace of the plane *P* (P_H). This horizontal line is brought to coincidence with the plane *H* in the following way. The vertical projection of this line intersects the vertical trace of the plane at point *v'* which is the vertical trace of the horizontal line. This trace is brought to coincidence with the plane *H* by describing an arc (from P_x as a centre and with a radius equal to $P_x v'$) to intersect the transformed vertical trace of the plane, P_{V_0}, at point v'_0. From this point a straight line is drawn parallel to P_H which is the transformed horizontal line passed through *B*. From the horizontal projection *b* of point *B* a perpendicular is erected to P_H to intersect the transformed horizontal line at point b'_1, which is the required point.

4. THE METHOD OF REPLACING PROJECTION PLANES

In this method one of the projection planes is replaced with a new one on which a given geometrical element (point, straight or curved line, plane figure) is projected. Contrary to the two foregoing methods, the method of replacing projection planes leaves the given geometrical element fixed in position. We may replace the plane *V* with another, V_1 (Fig. 168*a*), which is also perpendicular to the plane *H*.

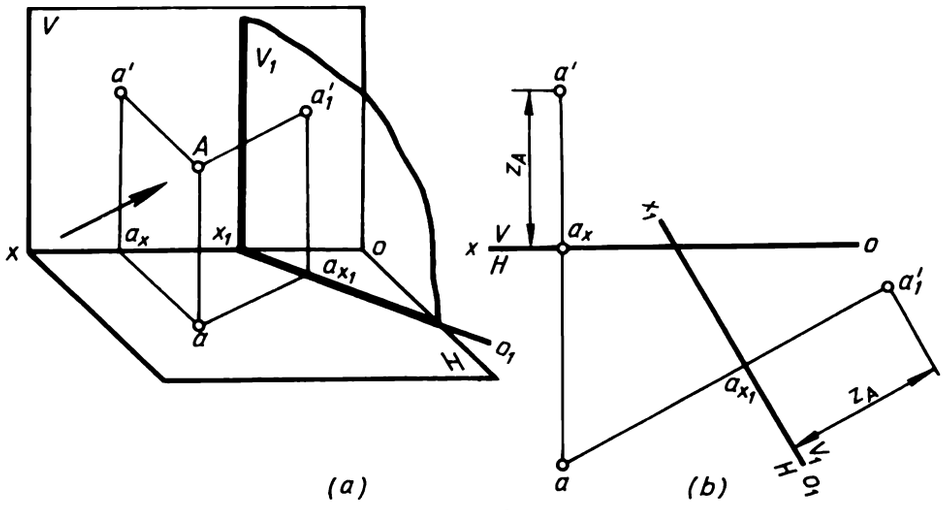


Fig. 168

The line along which the new plane V_1 intersects the plane H is the new axis of projection denoted in the drawing as o_1x_1.

The new system of the projection planes is denoted as $\frac{V_1}{H}$. Sometimes the plane H may also be replaced with another, usually denoted as H_1. Whereas the new plane V_1, like the old plane V, is vertical, the new plane H_1 will not be horizontal, but is called so conventionally.

In some cases the solution of specific problems on an orthographic drawing requires a double replacement of planes, for instance, the vertical and horizontal planes of projection are replaced, V_1 and H_1 being their substitutes.

As is seen from Fig. 168*a*, in replacing the plane V with a new one, V_1, the distance from the new vertical projection of point A (a'_1) to the new axis of projection o_1x_1 is equal to the distance from the replaced projection of this point (a') to the axis ox. This rule should be remembered and strictly observed in solving various problems using the method of replacing projection planes.

Hence, in replacing plane V with plane V_1 first draw the new axis of projection o_1x_1 and then construct the new vertical projection of the point (Fig. 168*b*). This is how it is done. From the horizontal projection of A (point a) drop a perpendicular to the new axis of projection o_1x_1. On the extension of this perpendicular lay off the coordinate z_A from the new axis of projection.

If the plane H is to be replaced, after choosing a new axis of projection o_1x_1 make the following constructions to determine the new horizontal projection a_1 of the point A (Fig. 169). From the vertical projection a' drop a perpendicular to the new axis o_1x_1 and on the extension of the perpendicular mark off the coordinate y_A of the point A.

Let us now employ the method of replacing projection planes for determining the true length of a straight line AB (the hood edge, Fig. 157). In this case a new projection plane V_1 or H_1 must be chosen so as to be parallel to AB. That is, AB must be either a vertical line (when replacing V with V_1) or a horizontal line (when replacing H with H_1).

This problem can be solved in two ways.

Ist alternate solution — by replacing the plane V with plane V_1 (Fig. 170*a*).

For the sake of simplicity the new axis of projection o_1x_1 should coincide with the horizontal projection ab of the line AB. The coordinate z_B is zero, since the given point B lies on the plane H; therefore the new vertical projection b'_1 coincides with the horizontal projection b.

The new vertical projection a'_1 of point A is found on the perpendicular erected to the new axis of projection o_1x_1 at point a. The length aa'_1 marked off on this perpendicular is equal to the distance of the former vertical projection a' of the point A from the axis ox, or to the coordinate z_A. Join points a'_1 and b'_1 by a straight line to obtain the true length of AB.

2nd alternate solution — by replacing the plane H with plane H_1 (Fig. 170*b*).

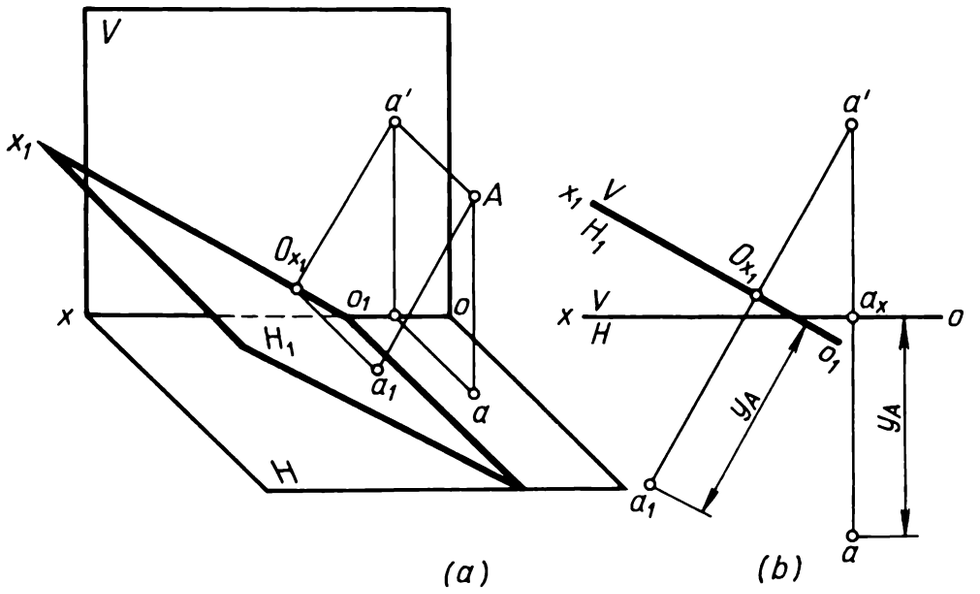


Fig. 169

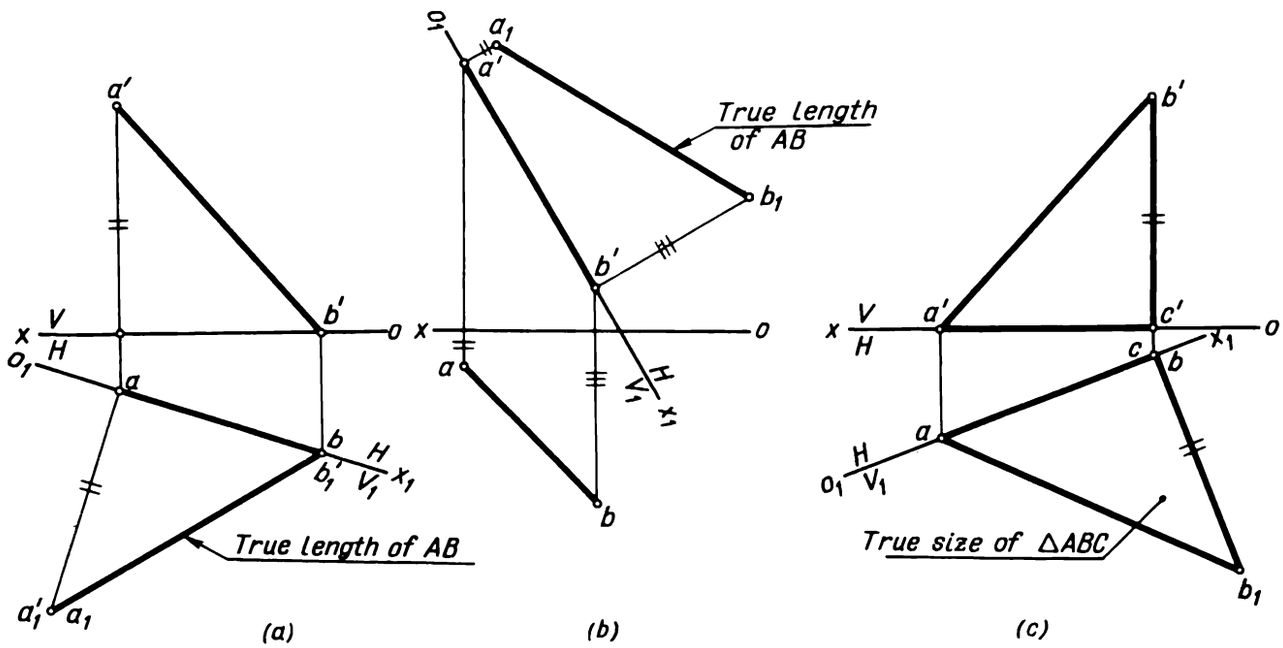


Fig. 170

Let us draw the new axis of projection through the vertical projection $a'b'$. The coordinate y_A is marked off on the perpendicular erected to o_1x_1 at point a', and y_B on the perpendicular erected to o_1x_1 at point b'. The points a_1 and b_1 thus obtained are the new horizontal projections of the points A and B. Join these points on the new "horizontal" plane of projection by a straight line to obtain the true length of the edge AB.

Determining the true size of a plane figure (say, a triangle) using the method of replacing projection planes. Let us take the rib ABC (see Fig. 160*b*) which represents a triangle contained in a horizontal projecting plane.

Here the plane V should be replaced with a

new plane V_1 to have the triangle *ABC* projected on this plane in true size. The new axis of projection o_1x_1 (Fig. 170*c*) should be drawn parallel to the line *abc*, which is the horizontal projection of the triangle, or (to simplify construction) should coincide with this line, as is shown in Fig. 170*c*. The simplification consists in that the new vertical projections of the points *A* and *C* (vertices of the triangle) will coincide with the new axis o_1x_1 and with the horizontal projections *a* and *c*, since they lie on the plane *H*. To determine the true size of the triangle it only remains to find the new vertical projection of its third vertex *B*. To this end do the following. Erect a perpendicular to o_1x_1 at *b*, the former horizontal projection of point *B*, and lay off on it the distance between *b'* and the axis *ox* to obtain point b_1. Then join the point b_1 with *a* and *c* by straight lines. The triangle ab_1c is the true size of *ABC*.

One more example is shown in Fig. 171. The curved plane figure is also contained in a horizontal projecting plane. Here, too, the plane *V* is replaced with V_1. For the sake of simplicity the new axis of projection o_1x_1 is drawn through the horizontal projection of the blade and it is brought to coincidence with the plane *H*.

To determine the true size of the blade outline construct the new vertical projections of a series of its points following the above considered method. For instance, to construct the new vertical projection of an arbitrary point *E* on the curve erect a perpendicular to the new axis of projection at point *e* which is the horizontal projection of the chosen point. Then mark off on the perpendicular the distance from the former vertical projection *e'* to the former axis *ox*, i.e., the coordinate z_E of the point *E*. The point e_1' thus obtained is the new vertical projection of *E*.

The method of replacing projection planes is frequently used to solve so-called *reverse problems*, namely: to construct the projections of a figure or to erect a perpendicular to a figure representing an oblique plane, given the true size of the figure.

Consider the solution of such a problem.

Shown in Fig. 172*a* is a picture of a holder with a boring tool. The body of the holder, having the shape of a rectangular parallelepiped, is cut by a plane, perpendicular to which a hole for the tool bit is made. In making the drawing of the holder there arises a problem: how to

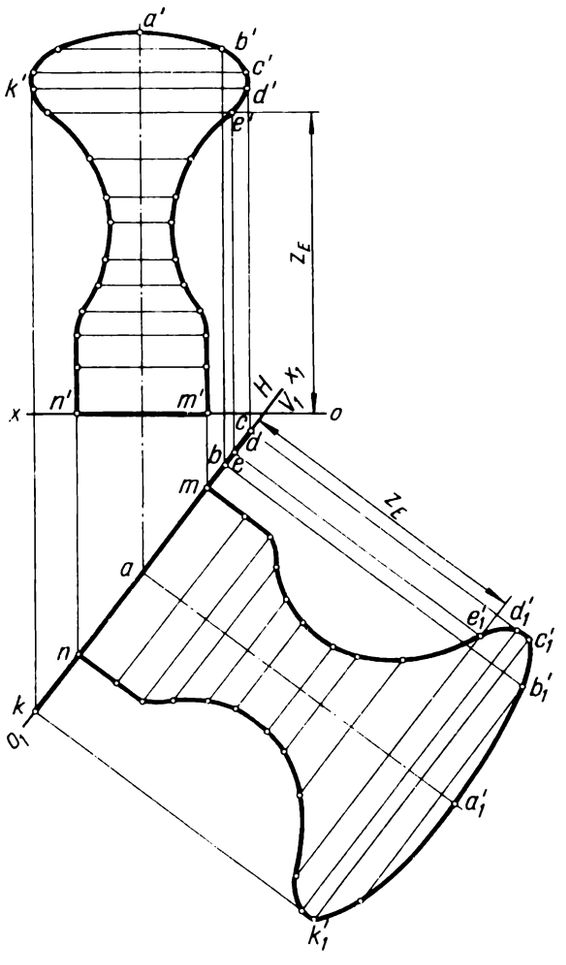


Fig. 171

determine the projections of the centre of the hole, and also, how to construct the axis of the hole which should be perpendicular to the cutting plane and pass through the centre of the circle inscribed in the triangle which bounds the cutting plane.

The following plan is suggested for solving the problem:

1. To replace one plane of projection with another in order to transform the cutting plane, containing the triangle *ABC*, into a projecting plane. For example, replace the plane *V* with V_1 to make the plane containing the triangle *ABC* perpendicular to the plane V_1, that is, to make it a vertical projecting plane.

2. To replace another plane of projection so that the plane containing the triangle *ABC* becomes parallel to the new plane of projection. For example, replace the plane *H* with plane

H_1 to make the plane containing *ABC* parallel to the plane H_1.

3. On the true image of the triangle construct the centre of the hole for the cutter (point *O*) and find its required projections (o', o) making use of reserve constructions.

4. Proceeding from the properties of projections of a straight line perpendicular to a plane, it is possible to construct the required projections of the perpendicular which must be perpendicular either to the corresponding traces of the triangle's plane or to the corresponding projections of the horizontal and vertical lines situated on the plane of this triangle.

This plan is realized in an orthographic drawing in the following way.

To make the plane of *ABC* a vertical projecting plane draw the new axis o_1x_1 (Fig. 172*b*) so that it is perpendicular to the horizontal projection of a horizontal line lying on the triangle's plane. Since the side *AB* of the triangle is such a horizontal line, the new axis of projection o_1x_1

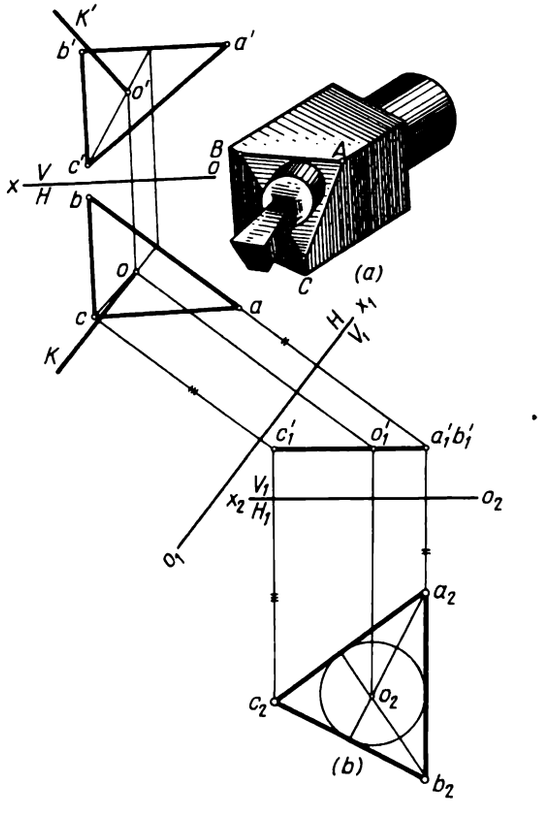


Fig. 172

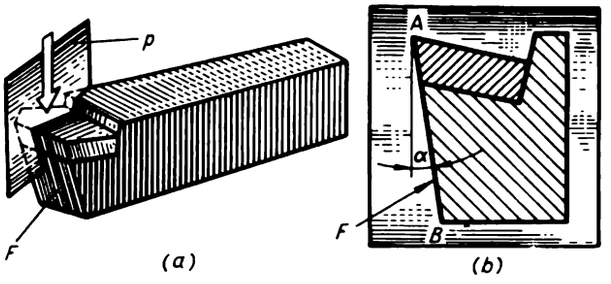


Fig. 173

is drawn perpendicular to *ab* at any random distance from the point *a* but not too close to it to avoid the overlapping of the old projections of the triangle and the new ones.

The new vertical projection of the triangle is constructed from the vertices *A*, *B*, and *C*. For instance, the new vertical projection b_1' of the vertex *B* is found on the perpendicular erected to the new axis of projection o_1x_1 at a distance equal to the distance of b' from the former axis of projection ox.

The new vertical projection c_1' of the vertex *C* is determined in the same manner. Since the plane containing the triangle is a vertical projecting plane, the new vertical projection $a_1'b_1'c_1'$ of the triangle will be a straight line.

To transform the plane of the triangle *ABC* into one parallel to the horizontal plane of projection draw a new axis of projection o_2x_2 parallel to the projection $a_1'b_1'c_1'$, not too far from it so as to provide enough space for the new projection of the triangle. Then find it in the following way. From the points a_1', b_1' and c_1' drop perpendiculars to the axis o_2x_2 and on their extensions mark off lengths equal to the distances from the former horizontal projections of the apices to the former axis of projection o_1x_1. Join the newly constructed horizontal projections a_2, b_2 and c_2 by straight lines to obtain the true size of the triangle *ABC*. Now inscribe a circle in the triangle and determine its centre. The point o_2 is the new horizontal projection of the centre.* Then find the vertical projection o_1' of the point *O*. It is obviously the point of intersection of the perpendicular dropped to o_2x_2 from o_2 and the line $a_1'b_1'c_1'$. This done, con-

* It is the point of intersection of the bisectors of the angles $B_2A_2C_2$, $A_2B_2C_2$, $A_2C_2B_2$. To construct a bisector, use one of the principal geometrical constructions: to divide an angle into two equal parts, considered in Part Two, Chapter 1.

struct the required horizontal projection, o, of the point O. To this end, from the obtained point o_1' drop a perpendicular to the axis o_1x_1 and lay off on its extension a length equal to the distance from o_2 to o_2x_2. Finally, with the aid of an auxiliary line co drawn in the triangle's plane determine the vertical projection, o', of the required point O.

Through the points o and o' thus obtained draw the projections of the perpendicular OK which is the axis of the tool bit. The projections of the axis OK are perpendicular to the like projections of the horizontal and vertical lines. In this case these projections are the sides AB and AC of the triangle ABC (AB is a horizontal line, AC being a vertical line).

Determination of the true size of an angle formed by two planes is illustrated in Fig. 173*a* and *b*. Shown in the figure is a turning tool. There are several ways to solve this problem, but one condition must be strictly observed, i.e., the tool's edges must be perpendicular to a projection plane which will show the required true size of the angle.

The face and flanks of the tool head form several specific angles. Let us determine the true size of the relief angle α.

What kind of angle is it and how is it obtained?

Let us place the tool with its base on the plane H and pass a so-called principal cutting plane P perpendicular to the horizontal projection of the cutting edge. The plane P will intersect the flank F along the straight line AB (Fig. 173*a*, *b*). Then the angle between the line AB and the vertical line drawn from A will be the relief angle α.

Since the cutting plane P is passed perpendicular to the plane H, it is a horizontal projecting plane.

Suppose the orthographic drawing of the tool is given (Fig. 174). To make the drawing simpler let us consider only the flank F of the tool and the vertical line drawn through the point A.

There is no difficulty in finding the projections of the vertical line on the drawing: the vertical projection $a'c'$ will be a vertical line, the horizontal projection ac being a point.

The projections of the line of intersection of the principal cutting plane P and the flank depicted as the given quadrangle $DEFG$ in the drawing are found in the following way. The horizontal projection of the intersection line ab coincides with the horizontal trace P_H of the plane; the

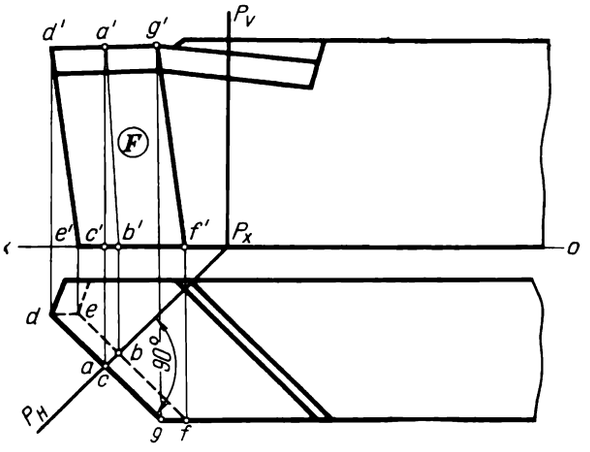


Fig. 174

vertical projection is the line $a'b'$, of which point a' is given. The point b' is constructed by projecting the point b on the axis ox (point B is contained in the plane H).

Let us determine the true size of the angle α using the method of replacing projection planes (Fig. 175*a*). To this end choose a new vertical plane of projection V_1 which must be parallel to the plane specified by the angle α. Since the plane containing the angle α is a horizontal projecting plane and is represented on the plane H as the straight line acb, the new axis of projection o_1x_1 is drawn parallel to acb. By dropping from b and c perpendiculars to the new axis o_1x_1 we obtain the new vertical projections b_1' and c_1' of the two points of the angle, B and C. The new vertical projection a_1' of the vertex A of the required angle is obtained by marking off on the perpendicular erected to o_1x_1 at c_1' a length equal to the distance from the vertical projection a' to the axis ox.

This problem can be solved by other methods of transforming projections.

Solution by the method of revolution (Fig. 175*b*).

The axis of revolution is the line passing through the vertex A of the angle α and perpendicular to the plane H. It coincides with the side AC of this angle. In transforming the angle its side AC remains fixed, only the side AB is revolved, that is, actually, only the point B, as the point A is also fixed. The plane of the angle α should be revolved until it occupies the position parallel to the plane V. After revolution the horizontal projection of the angle acb must be parallel to the axis ox.

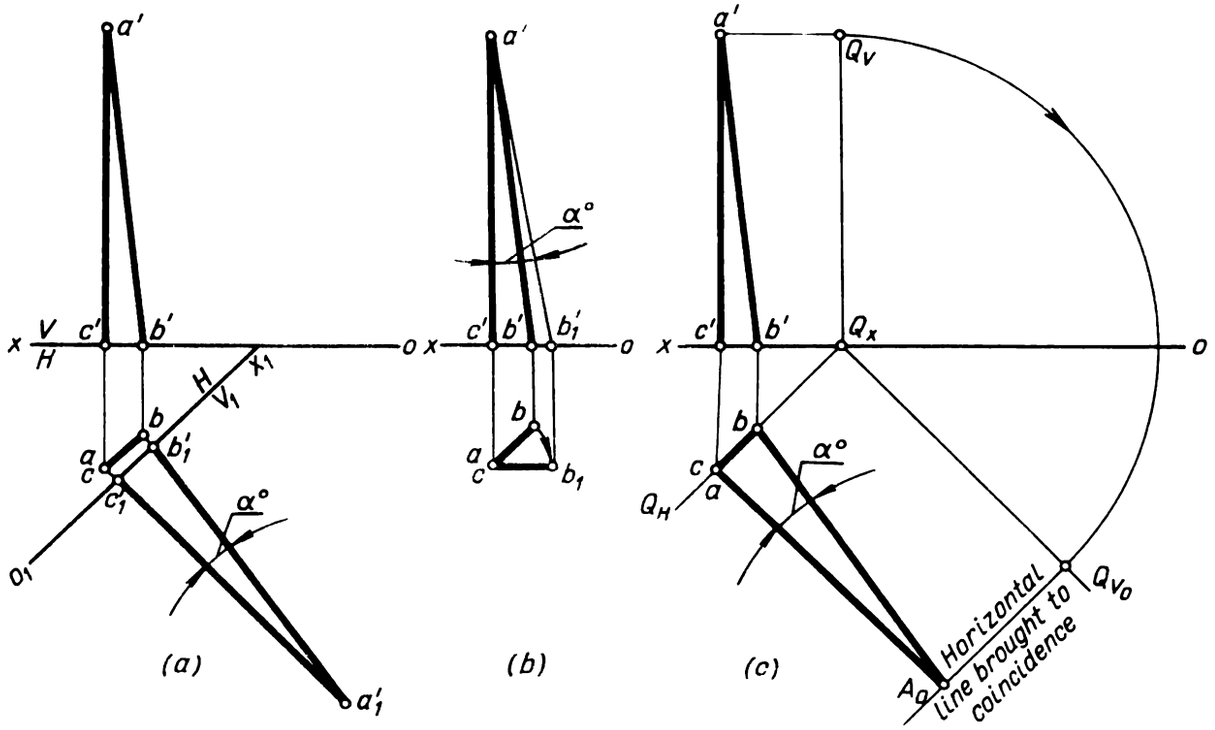


Fig. 175

Solution by the coincidence method (Fig. 175*c*).

Through the plane containing the angle *BAC* pass an auxiliary horizontal projecting plane Q and bring it, together with angle α, to coincide with the plane H. At the given position of the angle α it is sufficient to bring only the vertex of the angle A into coincidence with the plane H, since B and C are located on the axis of revolution, i.e., on the horizontal trace Q_H of the plane Q.

First bring the vertical trace Q_V into coincidence with the plane H to obtain the perpendicular Q_{V_0}, to the trace Q_H; then do the same with the auxiliary horizontal line drawn through the point A; and finally, bring into coincidence the vertex A which will be the point of intersection of the perpendicular erected to the trace Q_H from a and the newly obtained horizontal line.

5. OTHER SYSTEMS OF CONVENTIONAL DESIGNATION OF GEOMETRICAL ELEMENTS

There are other systems of conventional designation of projection planes, projections of points, lines and other geometrical elements, which differ from the system adopted in the present book. These include, for instance, the system used in many geometrical studies (say, in descriptive geometry) and adhered to by other authors of textbooks of drawing.

Cited below are examples from this system.

1. The planes of projection are designated in the following way (Fig. 176*a*):

Π_1 — the horizontal plane of projection;
Π_2 — the vertical plane of projection;
Π_3 — the profile plane of projection.

2. The origin of coordinates (the point of intersection of the axes of projection) is designated as o in a trihedral angle (Fig. 176*a*) and by the same letter with three subscripts (o_{123}) in a drawing (Fig. 176*b*). These subscripts imply that the point o belongs simultaneously to the three projection planes.

3. The axis of projection oz becomes z_{23}, since it is situated on two projection planes: the vertical plane with the subscript 2 and the profile plane, with 3.

4. Points in space are denoted by capital letters of the Latin alphabet:

A, B, C, D, E, F, G, etc.

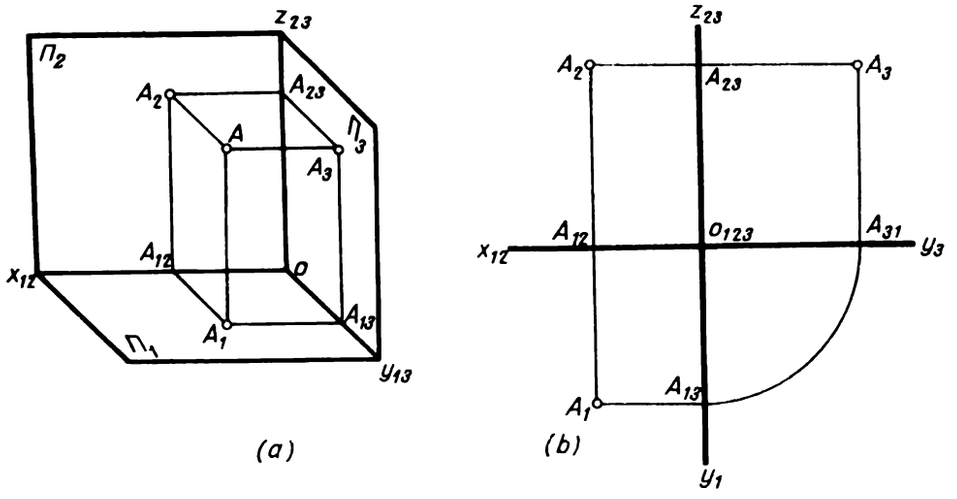


Fig. 176

5. Projections of points, lines and planes in a drawing are denoted by the same letters with a subscript 1, 2 or 3, depending on the projection plane on which they are constructed (see Fig. 176*b*):

on the plane $\Pi_1 = A_1$; b_1; Σ_1;
on the plane $\Pi_2 = A_2$; b_2; Σ_2;
on the plane $\Pi_3 = A_3$; b_3; Σ_3.

6. Lines, whether straight or curved, arbitrarily situated relative to the planes of projection are designated, when in space, by lower-case letters of the Latin alphabet:

$$a, b, c, d, e, \ldots, l, m, n, \ldots$$

7. Principal lines of a plane in space are denoted by the following letters:

horizontal lines — h;
vertical lines — f;
profile lines — p.

8. Planes (and surfaces in general) in space are designated by capital letters of the Greek alphabet:

$$\Gamma, E, H, \Theta, \Lambda, \Sigma, \Phi, \Omega, P, \ldots$$

9. Angles are designated by lower-case letters of the Greek alphabet:

$$\alpha, \beta, \gamma, \delta, \ldots$$

10. When replacing the Π plane with a new one, the latter is designated by the same letter with the corresponding subscript added, for instance, Π_4, Π_5.

11. In replacing the projection planes the new axis of projection is denoted by the letter s with the corresponding subscript, for example, s_{14}.

12. The axonometric axes are denoted as x', y', z', and the origin of coordinates as o'.

13. The axonometric projections of points, lines and planes are designated by the same letters as in space, but with primes:

$$A', a', \Omega'$$

Questions

1. Explain the fundamentals of the methods of revolution, coincidence, and replacing the planes of projection.
2. How is the true size of a triangle, contained in an oblique plane, determined using the coincidence method?
3. How many times and about which axes is it necessary to revolve a triangle contained in an oblique plane to determine its true size?
4. How many times and in what way is it necessary to replace the projection planes to determine the true size of a polygon situated on an oblique plane?
5. How, with the aid of horizontal and vertical lines contained in an oblique plane, are the projections of a triangle lying in this plane constructed, given this triangle brought into coincidence with the horizontal plane of projection?

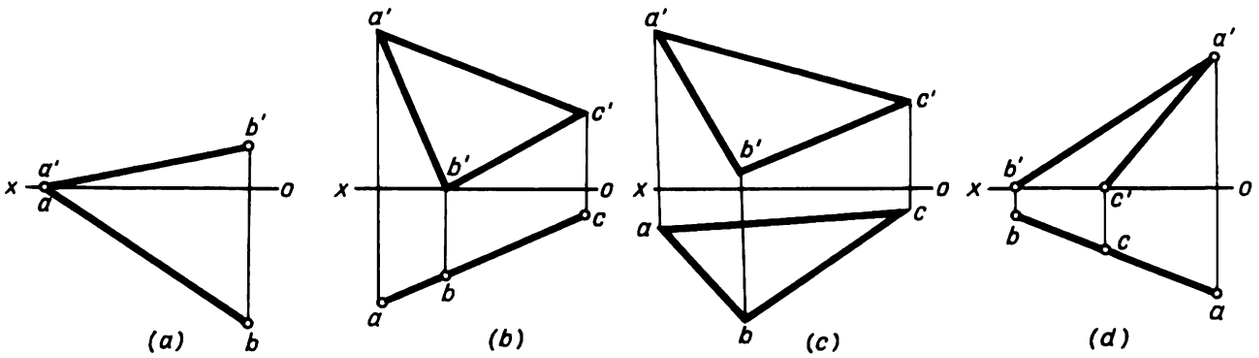


Fig. 177

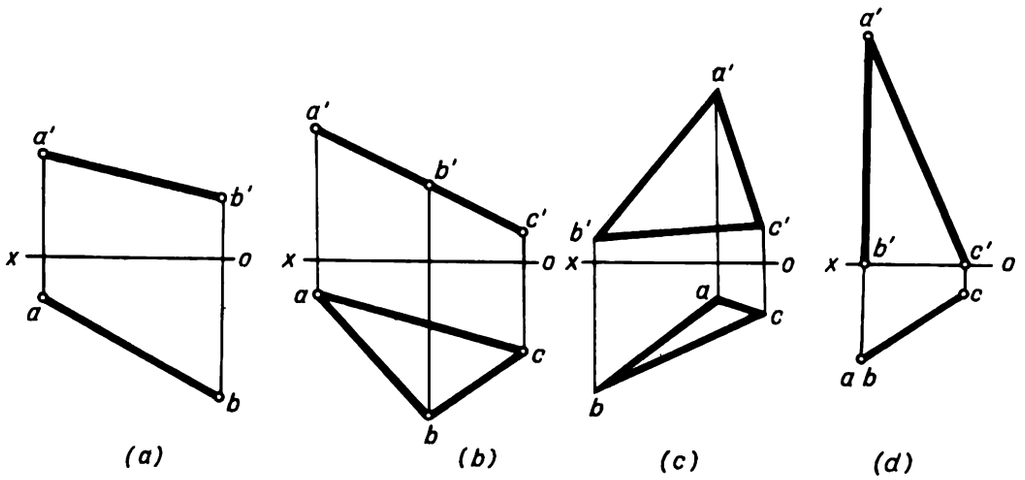


Fig. 178

Exercise 27

Determine the true length of the straight line *AB* in Fig. 177*a* using the method of revolution.

Exercise 28

Find the true size of the triangle *ABC* in Fig. 177*b* using the method of revolution.

Exercise 29

Find the true size of the triangle *ABC* in Fig. 177*c* using the method of revolution.

Exercise 30

Find the true size of the angle *BAC* in Fig. 177*d* using the method of revolution.

Exercise 31

Determine the true length of the line *AB* in Fig. 178*a* using the coincidence method.

Exercise 32

Find the true size of the triangle *ABC* in Fig. 178*b* using the coincidence method.

Exercise 33

Find the true size of the triangle *ABC* in Fig. 178*c* using the coincidence method.

Exercise 34

Find the true size of the angle *BAC* in Fig. 178*d* using the coincidence method.

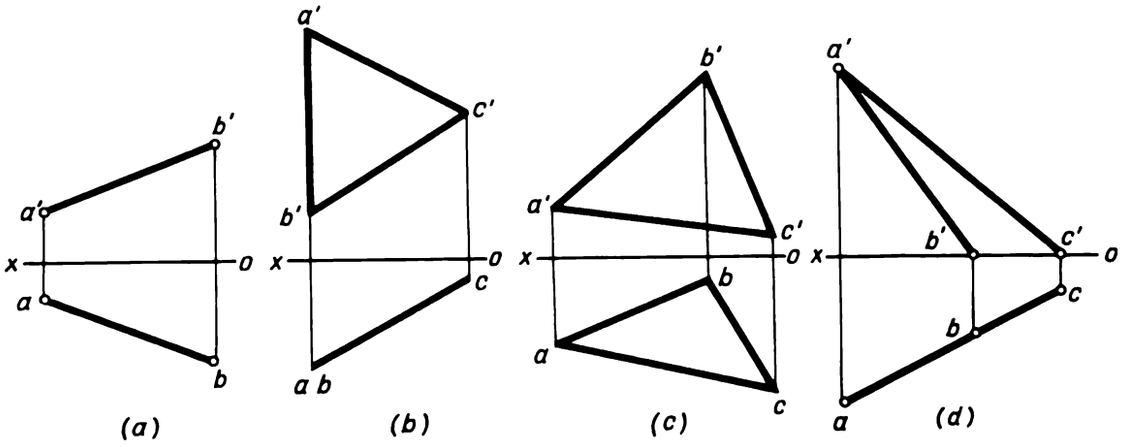


Fig. 179

Exercise 35

Determine the true length of the line *AB* in Fig. 179*a* using the method of replacing the projection planes.

Exercise 36

Find the true size of the triangle *ABC* in Fig. 179*b* using the method of replacing the projection planes.

Exercise 37

Find the true size of the triangle *ABC* in Fig. 179*c* using the method or replacing the projection planes.

Exercise 38

Find the true size of the angle *BAC* in Fig. 179*d* using the method of replacing the projection planes.

CHAPTER 6

AXONOMETRIC PROJECTIONS

1. TYPES AND METHODS OF AXONOMETRIC PROJECTION

Axonometric projections are widely used in engineering due to their pictorial force and simplicity of construction.

Axonometric projections differ from orthographic (orthogonal) projections (see Fig. 180*a*) in that in axonometry* an object is projected only onto one plane of projection *P*, called the axonometric (or picture) plane, and is placed in front of the picture plane *P* so as to expose three sides, *A*, *B*, and *C*, to the viewer (Fig. 180*b*).

Exercises in constructing axonometric projections of objects help a great deal in acquiring the skill of reading and understanding the language of engineering drawings, as well as in developing the ability to visualize the shapes of three-dimensional objects and to feel the proportions of machine parts.

In mechanical engineering axonometric projections are used as an auxiliary to orthographic projections of a mechanical part when the necessity is felt to give a clearer picture of its shapes which are difficult to visualize from the orthographic projections.

Considering the example given in Fig. 180 it is difficult to overestimate the advantages of the axonometric projection (Fig. 180*b*) over the orthographic projections of the same object (Fig. 180*a*) from the viewpoint of pictorialness.

Without the axonometric picture it is very

* The word 'axonometry' (Greek) consists of two words: 'axon' — axis and 'metreo' — I measure, and means 'measuring with the aid of axes', or 'measuring along axes'.

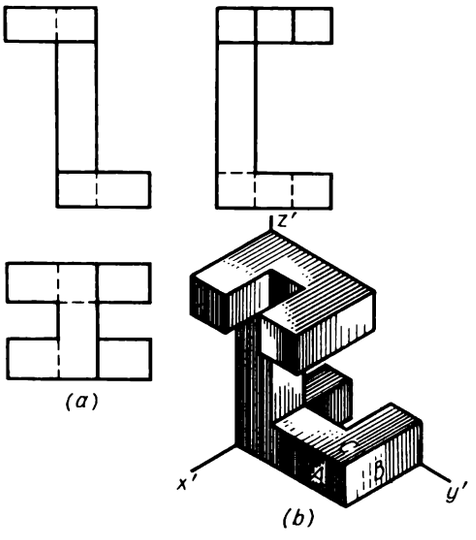


Fig. 180

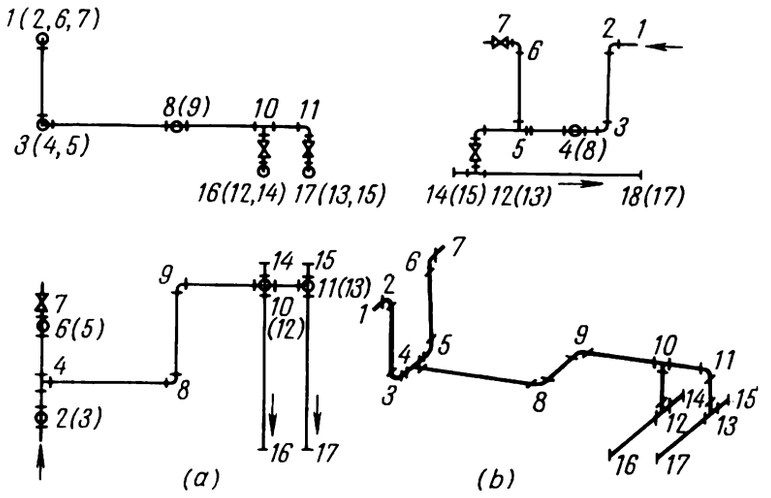


Fig. 181

difficult to visualize the shape of the object from the three orthographic projections alone (Fig. 180*a*).

Axonometric projections of individual complicated parts or of a whole unit are often of great help in designing and developing new products.

Axonometric projections of various piping networks and their diagrams are extremely pictorial. It is very difficult to read orthographic projections of piping network diagrams (see Fig. 181*a*), especially where sections of piping are situated in a vertical or a horizontal plane, since their projections overlap. The axonometric projection of the same piping (given in Fig. 181*b*) makes it possible to easily realize the relative positions of the various sections of piping.

Axonometric projections have a great advantage over perspective representation of objects which distorts dimensions, takes a lot of time and involves many difficulties (see Fig. 113*a*).

Axonometric projections are obtained on the projection plane by the usual method of projecting, i.e. by drawing projecting rays through each point of the object to intersect the projection plane (see Fig. 113*b*).

If the projecting rays are perpendicular to the axonometric plane of projection, then we have a *rectangular axonometric projection.*

If the projecting rays are mutually parallel and are inclined at an angle α to the axonometric plane of projection, we have an *oblique axonometric projection.*

The USSR Standard recommends the use of the following three types of axonometric projection: *rectangular isometry* (Fig. 182*a-c*), *rectangular dimetry* (Fig. 183*a-c*) and *oblique frontal dimetry* (Fig. 184*a-c*).

Shown on these figures are the simplest geometrical solid (a cube) and a mechanical part of simple shape in different positions relative to the axes of coordinates. Considered below are the methods of constructing the various axonometric projections of these objects.

An axonometric projection of a cube can be obtained in much the same way as an orthographic projection provided:

(a) the points (vertices of the cube) are projected on one plane of projection (the plane V);

(b) the cube is placed in front of this plane so as to make it possible for three of its faces (two vertical and one horizontal) to be represented on a single plane of projection;

(c) the three axes are conventionally represented (see Figs. 182*b*, 183*b* and 184*b*).

2. ORTHOGRAPHIC ISOMETRIC PROJECTIONS

To construct an isometric projection of the cube, with its orthographic drawing given, with the faces parallel and perpendicular to the plane of projection, first turn the cube about the vertical axis (perpendicular to the plane H) through an angle of 45° (Fig. 185*a*, for the sake of simplicity the cube is placed on the plane H). Then turn the cube for a second time, now about the

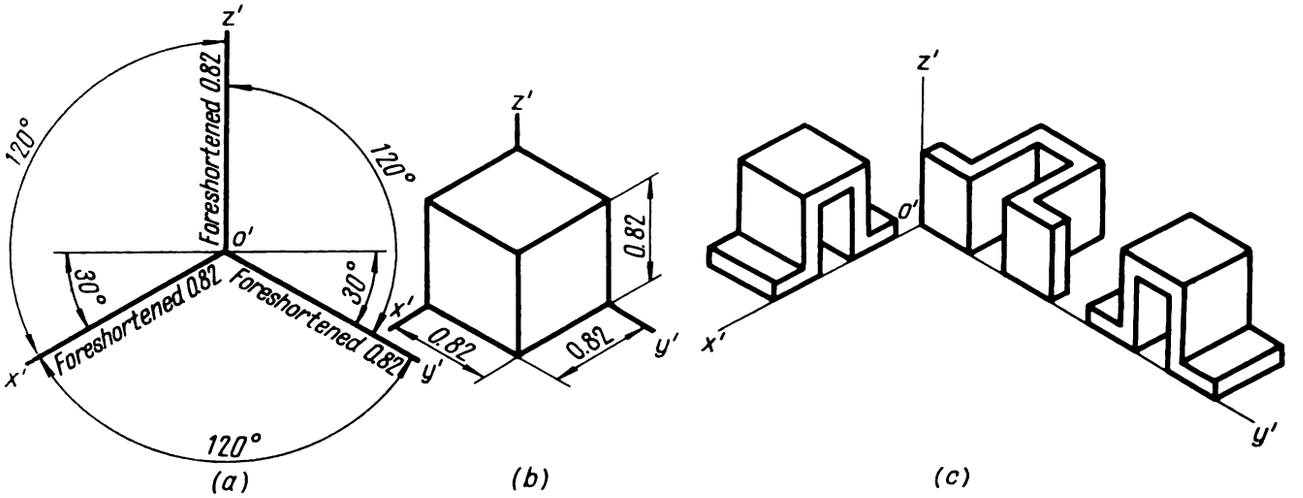


Fig. 182

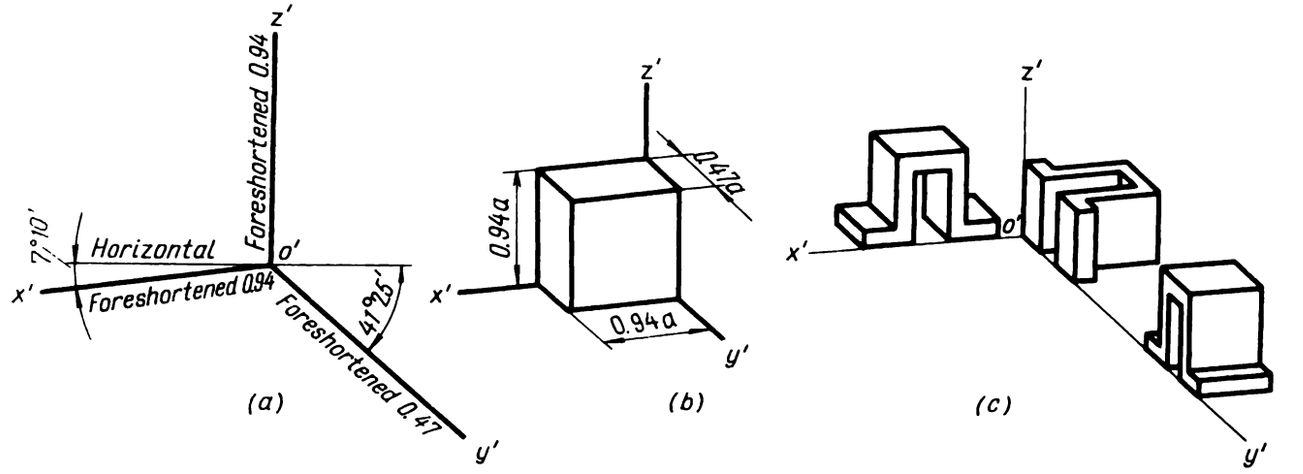


Fig. 183

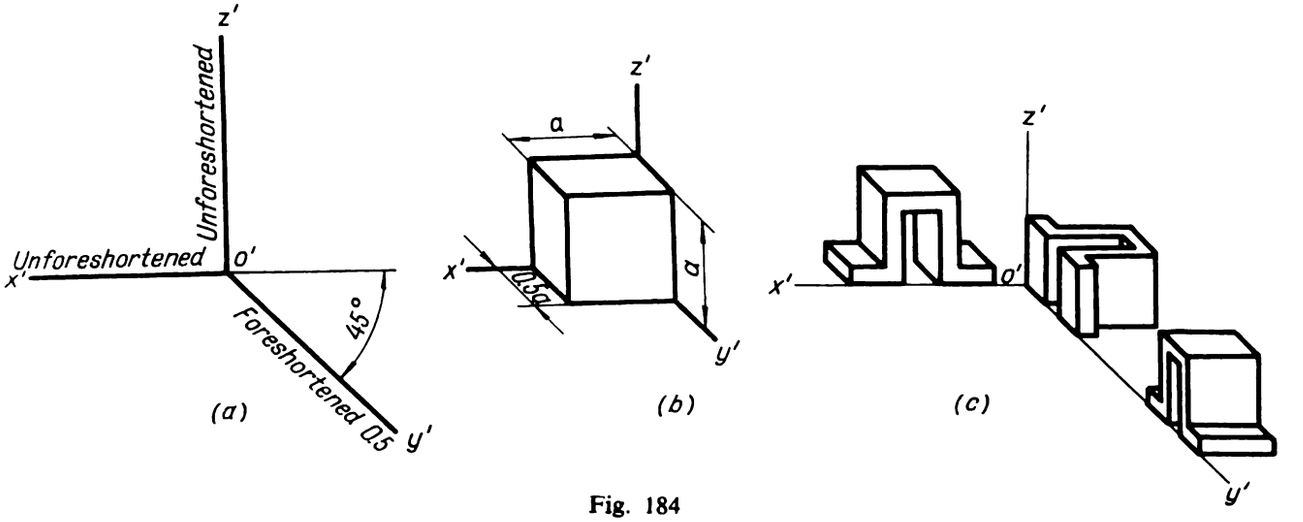


Fig. 184

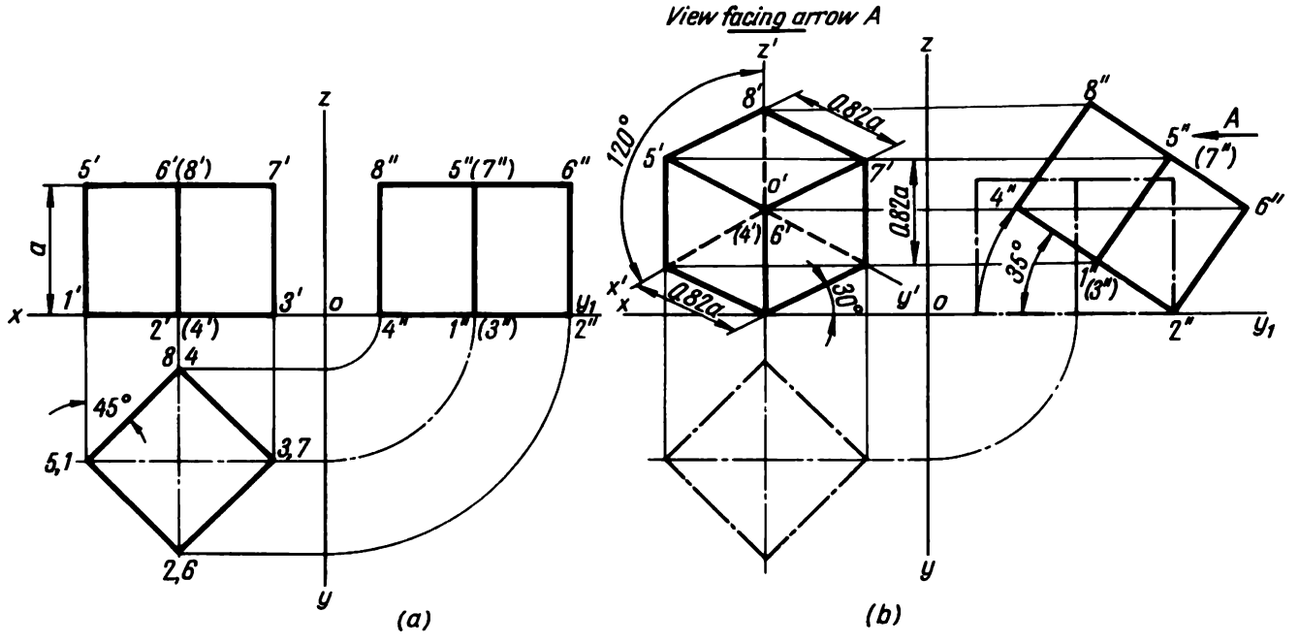


Fig. 185

horizontal axis (which is perpendicular to the plane W) through an angle of 35° (to be more precise, 35° 16′, see Fig. 185*b*). The procedure of turning the cube becomes very simple if a line passing through vertex *2* of the cube and lying on the plane H parallel to the plane V is chosen as the axis of revolution. At this the diagonal *4-6* becomes perpendicular to the plane V and coincides with the direction of projecting in isometry. Then we shall obtain the isometric projection of the cube on the plane V (Fig. 185*b*).

As is seen from the figure, the edges of the cube which were parallel to the axes *ox*, *oy*, *oz* in the orthographic projection are now at an angle of 120° to each other, their length becomes foreshortened to 0.82 of their true length.

Considering the obtained isometric projection of the cube together with the isometric axes $o'x'$, $o'y'$, $o'z'$ we may draw the following conclusions:

(a) the axes $o'x'$, $o'y'$, $o'z'$ are at 120° with each other;

(b) to construct an isometric projection of an object (say, a cube) the straight lines which are parallel to the orthographic axes *ox*, *oy*, *oz* must be laid off in directions parallel to the axes of isometry, $o'x'$, $o'y'$, $o'z'$;

(c) the length of straight lines is foreshortened and equals 0.82 of their true length.

To make the construction simpler, this foreshortening is not observed in engineering drawing: the true length of lines is marked off parallel to the axes.

Objects may be placed in different positions relative to the plane of projection (see Fig. 182*c*).

The isometric axes $o'x'$, $o'y'$, $o'z'$ as well as straight lines parallel to them are very easily drawn with the aid of a 30°-60° triangle. Fig. 186 illustrates its use.

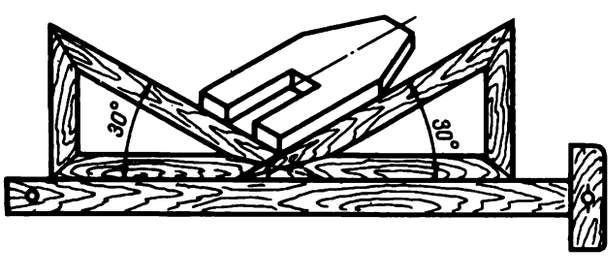


Fig. 186

3. CONSTRUCTING PLANE FIGURES IN ISOMETRY

Each surface of an object is generated by a line, and each line by a point. That is why we shall begin constructing isometric projections with a point.

Suppose the orthographic projections of a point A are given (Fig. 187*a*) and the isometric projections of this point are required. Begin the construction with drawing the coordinate axes $o'x'$, $o'y'$, $o'z'$ at 120° with each other (Fig. 187*b*). From the origin of coordinates (point o') and on the axis $o'x'$ lay off the length $o'-1$ equal to the coordinate x_A. Through point *1* draw a line parallel to the axis $o'y'$ and mark off on it the length $1-2$ which is equal to the coordinate y_A. From point *2* draw a line parallel to the axis $o'z'$ and mark off on it the length $2-A_1$ which is equal to the coordinate z_A. The point A_1 thus obtained is the required isometric projection of the given point.

An isometric projection of an equilateral triangle, hexagon and other figures (Fig. 188) can be constructed from its vertices.

In drawings, plane figures are frequently situated on the planes of projection or on planes parallel to them. In this case isometric construction becomes somewhat easier, since one of the coordinates of all the vertices will be the same, equal to zero or to a constant value.

Here are some examples:

(1) Consider the equilateral triangle $B_1C_1D_1$ in Fig. 188*a* contained in a plane parallel to the plane W *(zoy)* and with the base B_1D_1 lying on the plane H. The x coordinates of all its vertices are equal, while the coordinates z of B_1 and D_1 are zero.

The equilateral triangle *I* whose plane is parallel to the plane V has equal coordinates y for all its vertices and zero coordinates z for the vertices lying on the plane H. The triangle *III* which is parallel to the plane H has equal coordinates z for all its vertices and zero coordinates x for two vertices.

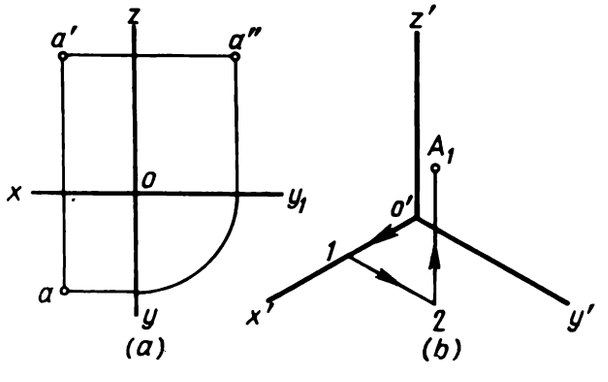


Fig. 187

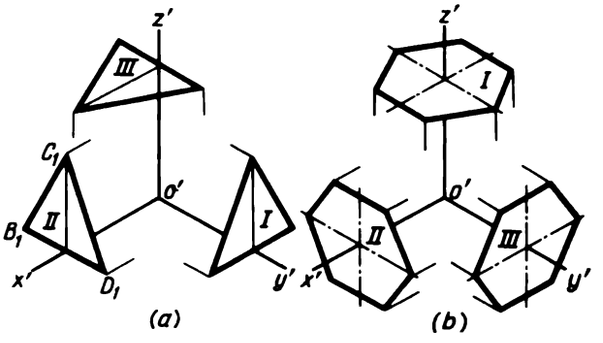


Fig. 188

(2) Fig. 188*b* illustrates the construction of a regular hexagon in isometry with the axes of coordinates passing through the points of intersection of the axes of symmetry of the figure.

Isometric projections of geometrical solids—prism and pyramid—are constructed in the following sequence (Fig. 189*a* and *b*).

First construct the isometric projections of the base using the above considered method (as in Fig. 188). Then construct the isometric projections of the edges and second base. In the case of the pyramid, construct the height and find the vertex. If the pyramid is truncated, construct its second base and draw the edges.

If the base of a prism or a pyramid is a regular polygon (say, a hexagon as in Fig. 189*a* and *b*), the construction of the vertices of the base from their coordinates can be simplified by drawing one of the coordinate axes through the centres of the bases. In Fig. 189*a*, *b* the axis $o'z'$ is drawn through the centres of the bases of the prism and pyramid which are regular hexagons, while the axis $o'y'$ passes through the centre of the base of the prism (Fig. 189*d*).

One of the faces of the right trihedral prism (Fig. 189*c*) lies on the axis $o'x'$, thus making its construction simple, since the coordinates z of the four points of the face parallel to the plane H are equal to zero.

The interior of hollow objects is shown in axonometry by means of sections (Fig. 189*e*). The object is conventionally cut by planes parallel to the planes of projection (see Fig. 190).

If the object has axes of symmetry, for example, the hollow tetrahedral prism presented in Fig. 190*a*, then a quarter of the prism can be cut away by two planes. Shown in Fig. 190*b* is a prism cut by a vertical *(P)* and a horizontal

(K) plane, while in Fig. 190*c* it is cut by a vertical (P_2) and a profile (P_1) plane.

The cutting planes in axonometry should be chosen so as to present a clear picture of the required sections.

The sections produced by the cutting plane are cross-hatched with thin parallel lines. The slant of the hatching lines is determined by laying off, on the axes $o'x'$, $o'y'$, $o'z'$, equal lengths from the origin of coordinates o and joining the points thus obtained by straight lines (Fig. 191).

Shown in the figure is the direction of cross-hatching lines depending on which cutting plane produces the section. If the cutting plane is parallel to the plane V or to the axes $o'x'$ and $o'z'$, then the cross-hatching lines are drawn parallel to the direction $\alpha\beta$.

If the cutting plane is parallel to the plane W, then the cross-hatching lines must be parallel

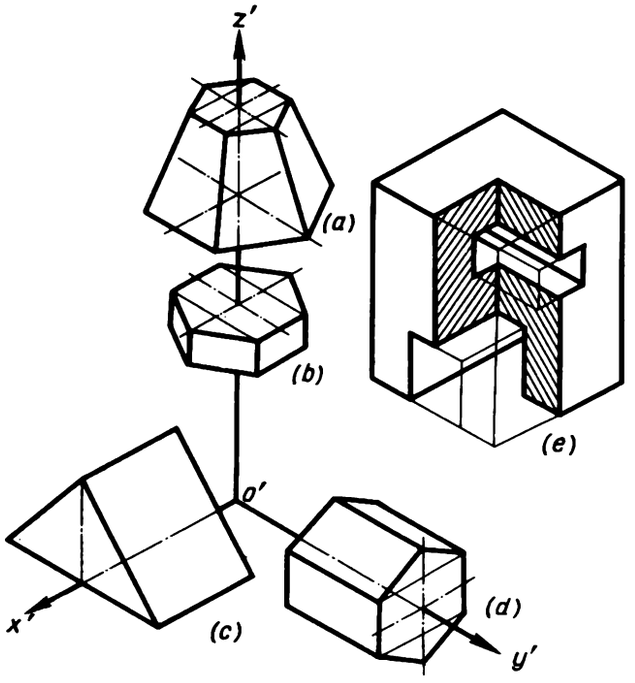


Fig. 189

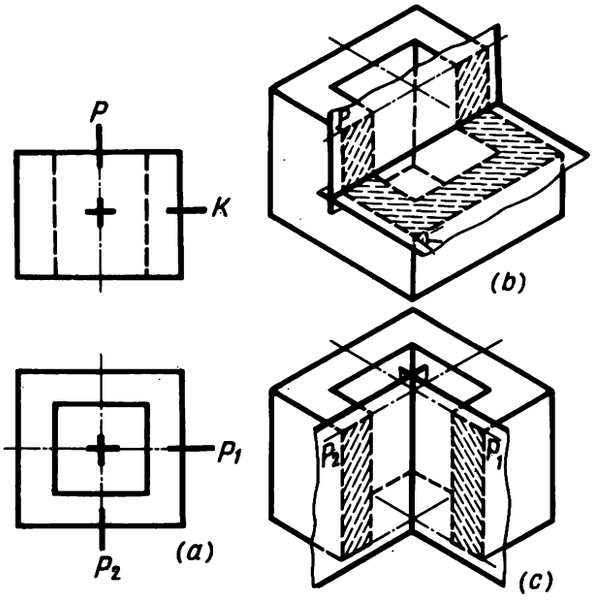


Fig. 190

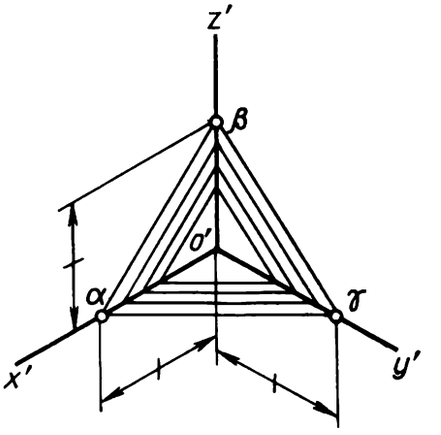


Fig. 191

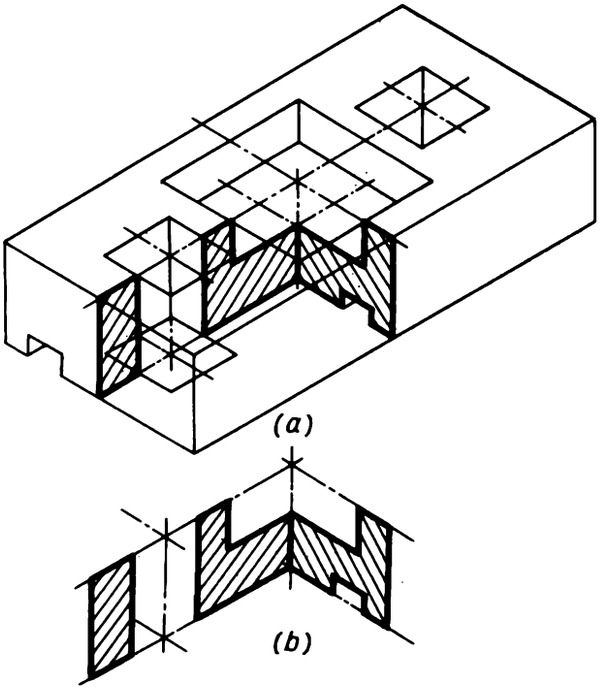


Fig. 192

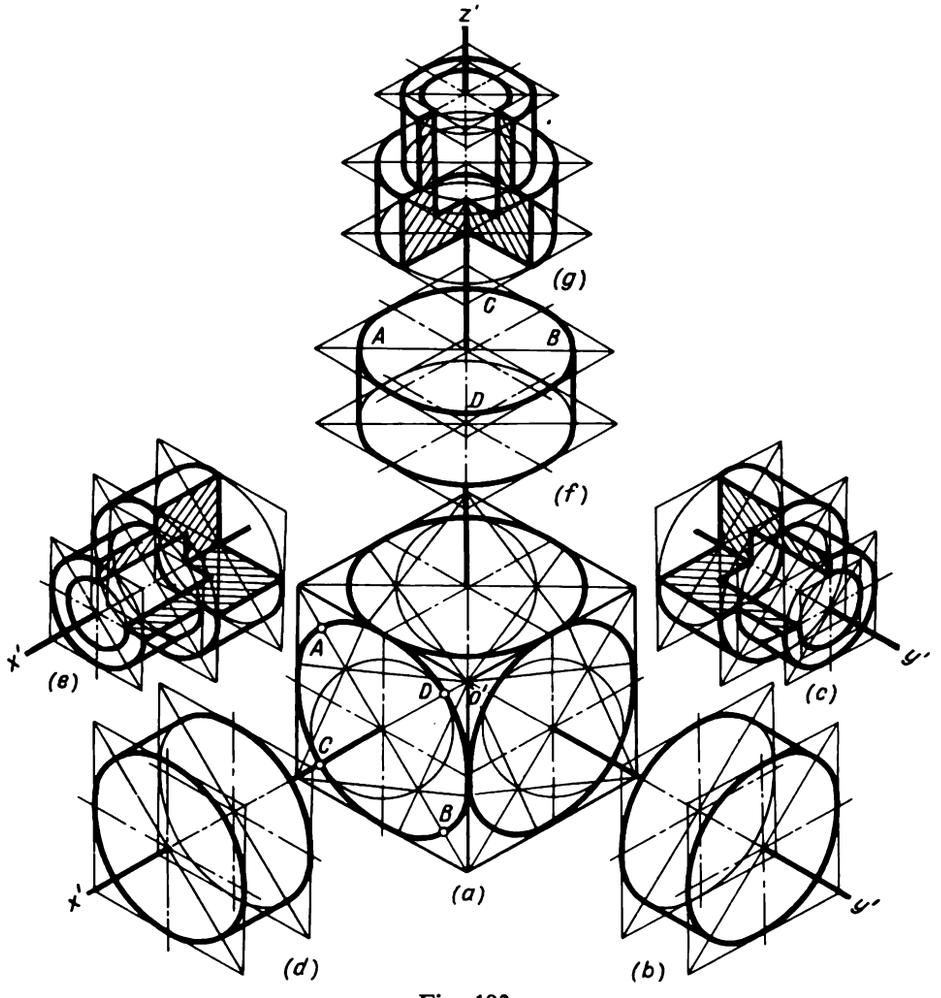


Fig. 193

to the line $\beta\gamma$. Sections obtained by horizontal planes (parallel to the plane H) are to be cross-hatched with horizontal lines (parallel to the line $\alpha\gamma$).

Axonometric sections can be constructed by the following two methods.

First method (Fig. 192*a*). Construct the axonometric projection of the whole object. Then the required section is obtained by cutting away the portion contained within the space bounded by the cutting planes.

Second method. With the orthograpic drawing of the object given, first construct the axonometric projections of the sections and then complete the projection of the object (Fig. 192*b*).

This method makes the construction simple, avoids many construction lines and is a useful exercise in visualizing shapes and images of an object as a whole, as well as its individual parts.

Circles contained in planes parallel to the principal planes of projection are represented in isometry as ellipses. It should be remembered that the minor axis of an ellipse should always be perpendicular to the major axis.

If a circle is contained in a plane parallel to the plane H (see Fig. 193*f*, *g*), then the ellipse must have a horizontal major axis *(AB)* and a vertical minor axis *(CD)*. If a circle is contained in a plane parallel to the plane V (Fig. 193*a*, *b*, *c*), the major axis must be drawn at 90° to the axis $o'y'$.

If a circle is contained in a plane parallel to the plane W (Fig. 193*a*, *d*, *e*), then the major axis is at 90° to the axis $o'x'$.

If the circles are assumed to be inscribed into squares, whose isometric projections are rhombs, then the major axes of the above ellipses will be directed along the larger diagonals of these rhombs (see Fig. 193*a*, *b*, *d*, *f*).

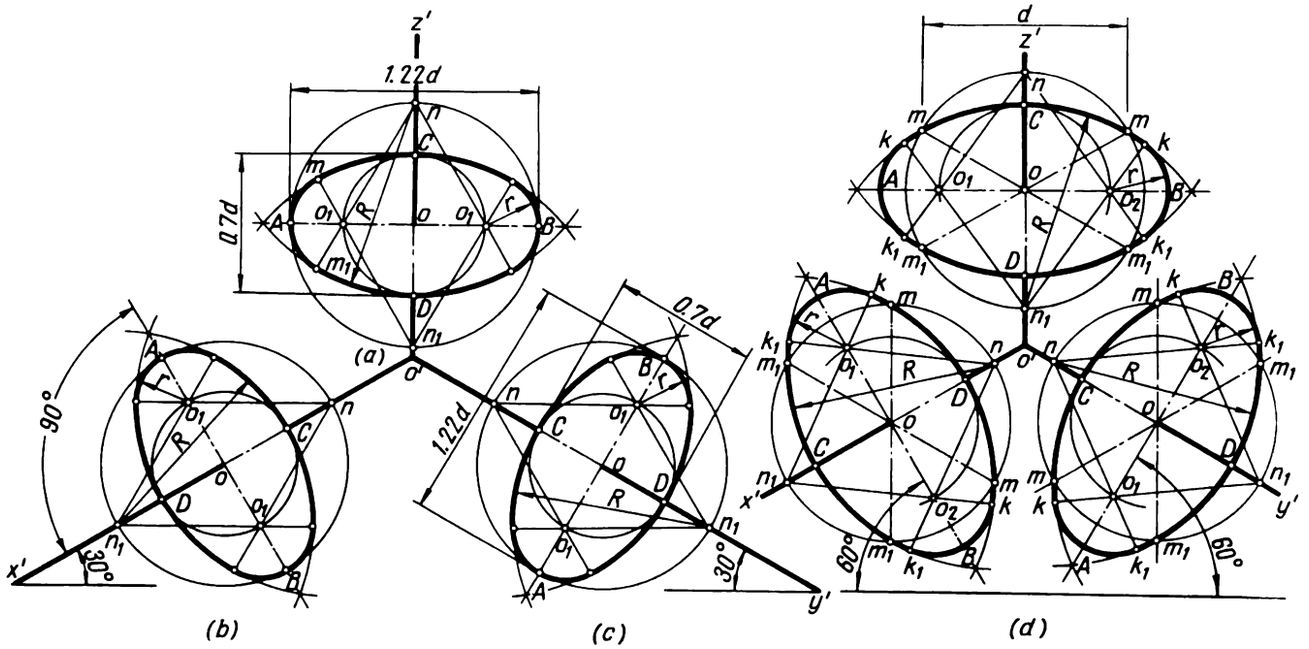


Fig. 194

In constructing an isometric projection of a circle without foreshortening along the axes $o'x'$, $o'y'$, and $o'z'$ the length of the major axis of the ellipse should be taken as equal to 1.22 d of the required circle (Fig. 194*a*, *b*, *c*), and that of the minor axis as equal to 0.7 d (Fig. 194*a*, *b*, *c*).

The USSR Standard recommends replacing true ellipses with ovals constructed by the four-centre approximate method.

The method of constructing ovals in isometry is shown in Fig. 194*a*, *b*, *c*.

Draw the axes, denoting the point of their intersection by the letter o (Fig. 194*a*). From o as a centre and with radii equal to half the length of the major and minor axes, respectively, describe two concentric circles to intersect the major axis with the smaller circle at points o_1 and the minor axis with the larger circle at points n and n_1.

From the points n and n_1 and with radii equal to Dn and Cn_1, respectively, describe two arcs to be brought to tangency with arcs drawn from o_1 as a centre and with radius $r = o_1m$.

If the circles are situated parallel to the planes V and W, then the major axes of the ovals will be perpendicular to the axes $o'x'$ and $o'y'$, respectively (Fig. 194*b*, *c*). These ovals are constructed in a way similar to that illustrated in Fig. 194*a*.

Presented in Fig 194*d* is another method of constructing ovals.

Draw the major axes AB of the ovals perpendicular to the isometric axes $o'x'$, $o'y'$, $o'z'$; through the centres of the ovals draw straight lines mm_1 parallel to the isometric axes. With o as centres and diameters equal to d describe circles to intersect the isometric axes at points n and n_1. From these points describe arcs through the points m to construct the ovals. The find points o_1 and o_2, the centres of the tangent arcs, mark off line-segments equal to half the length of the minor axis of the oval on both sides of the centre o.

Fig. 193*b*, *d* and *f* .ows the construction of ovals for cylinders, while Fig. 193*c*, *d* and *e* illustrates a hollow part (cup), its sections being cross-hatched.

If a portion of an ellipse or an oval is required in constructing axonometric projections of mechanical parts, first it is necessary to draw a complete ellipse or oval. If the radius of curvature is too long, an ellipse, or a part thereof, is constructed from points to be determined from their coordinates.

Shown in Fig. 195*a* is a machine part where the circles of the holes are parallel to the plane H; the circles of the nut (Fig. 195*b*) are parallel to the plane V, and in the machine part pre-

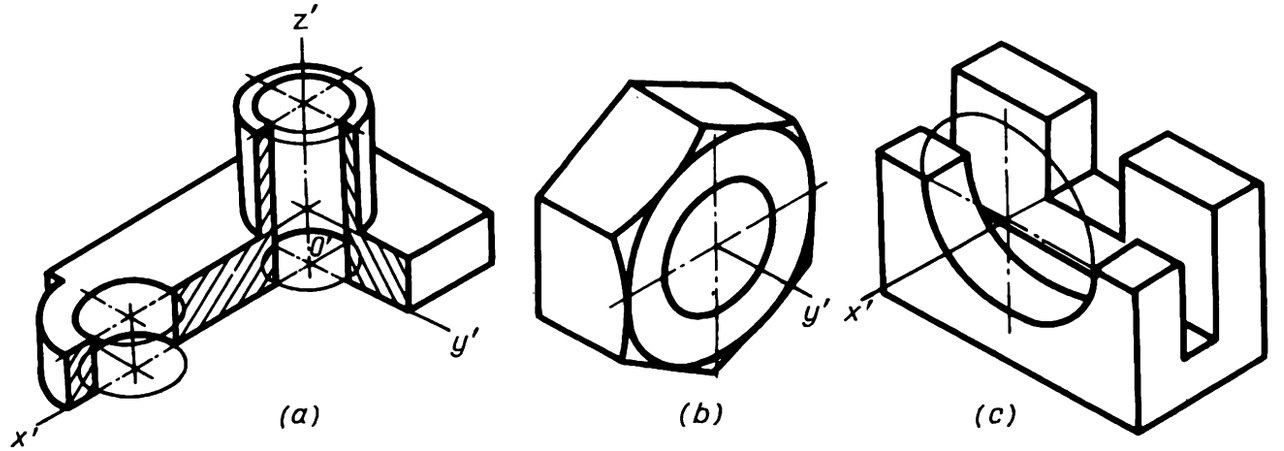


Fig. 195

sented in Fig. 195*c* the arc of the circle is parallel to the plane *W*. These are examples illustrating the construction of circles in isometry.

An isometric projection of a sphere cut by several planes parallel to the projection planes *H*, *V*, and *W* (Fig. 196) is constructed in the following sequence.

Draw the axes and with the origin of coordinates as a centre describe a circle, whose diameter is equal to 1.22*d*, where *d* is the diameter of the sphere (Fig. 196*a*). The sections, cut by planes parallel to the planes *V* and *H*, are constructed in the shape of two ellipses or ovals. The visible outlines must be finished in heavy lines, the sections cross-hatched, and the construction lines erased.

Fig. 196*b* illustrates a sphere cut by four planes: two horizontal, one vertical and one

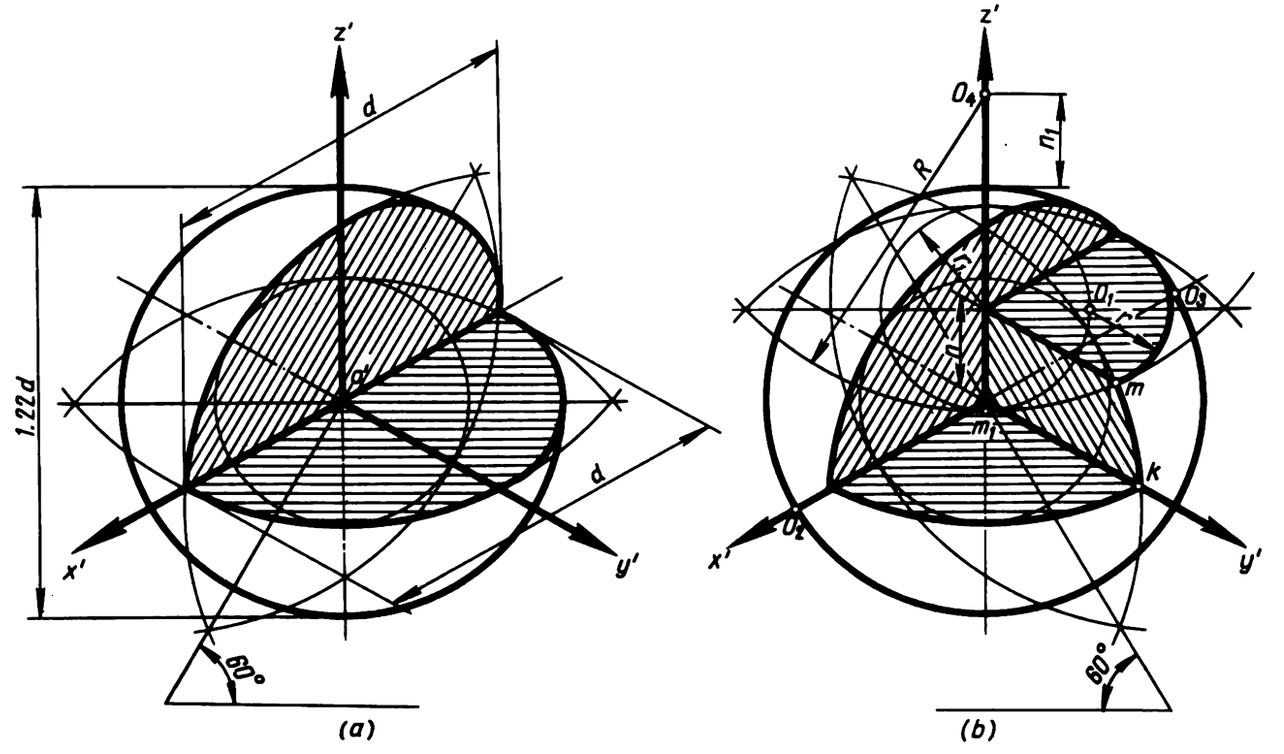


Fig. 196

profile plane. The constructions are carried out in much the same way as in the previous case. The section cut by the upper horizontal plane will be limited by a straight line parallel to the axis $o'x'$. In this case each curved line will be a part of an ellipse or of its substitute, an oval.

An isometric projection of a model or a machine part is constructed in the following way:

(a) explode the part imaginarily into separate elements bounded by regular geometrical surfaces (or parts thereof, which is more frequent in practice): plane, cylindrical, conic, spheric, and toroidal;

(b) construct the isometric projections of these elements with thin lines;

(c) erase construction lines;

(d) for a hollow part, construct all the necessary sections and cross-hatch them;

(e) to make the projection more graphic, add surface shading (see below).

If a machine part has plane curved outlines, as those shown in Fig. 197*a*, *b*, then these outlines are to be situated, as a rule, in a plane parallel to one of the projection planes, H, V, or W. The curved outline is constructed point by point from coordinates.

Examples illustrating the construction of machine parts having curved outlines in isometry are given in Fig. 197*c* and *d*.

In constructing an isometric projection of the cam shown in Fig. 197*b*, first draw the orthographic projection of its outlines on the profile plane of projection (since the plane of the cam is parallel to the plane W). Then mark a series of points with coordinates y and z and construct an isometric projection of these points from their coordinates. To construct, for in-

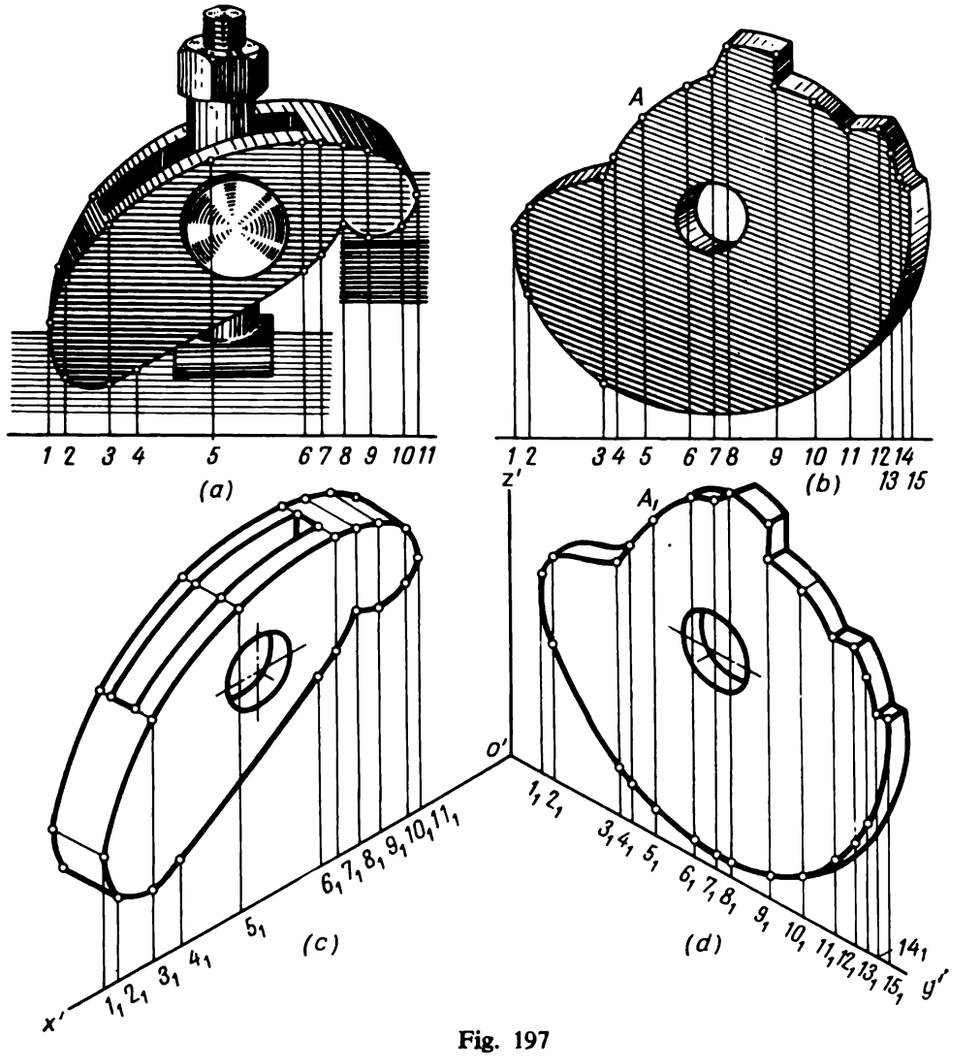


Fig. 197

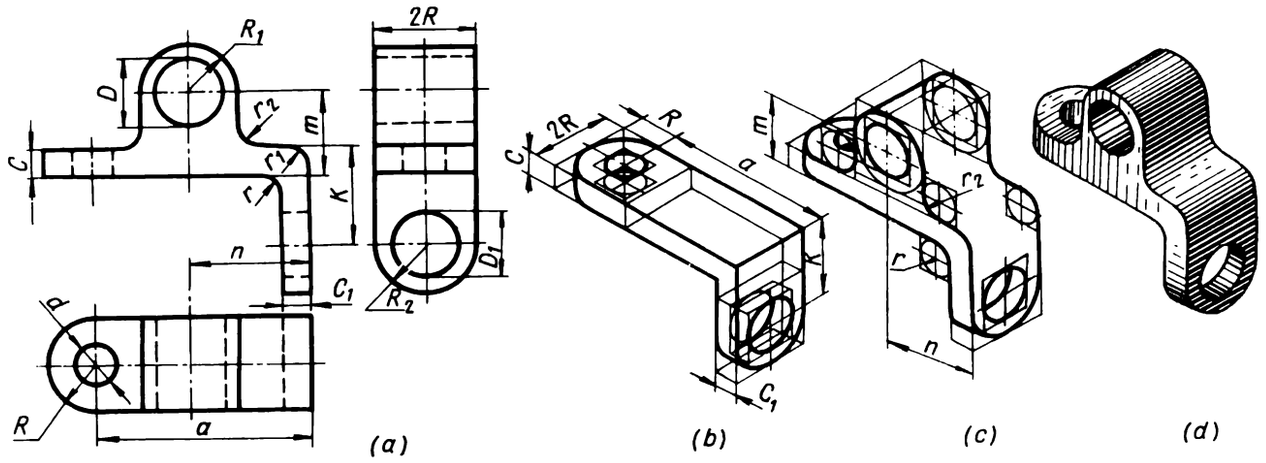


Fig. 198

stance, the point A in isometry proceed as follows. Mark off on the axis $o'y'$ the coordinate y_A of the chosen point, the length o'-5_1, and, through point 5_1 draw a line parallel to the axis $o'z'$; then lay off on it the second coordinate of A, the length 5_1-A_1 equal to 5-A.

Let us consider the process of constructing an isometric projection of the bracket in Fig. 198*a* with its orthographic projection given.

Divide it into two pieces: a lower and an upper one. Construct (in thin lines) the lower piece with its circles and semi-circles (Fig. 198*b*). Then, on laying off the thicknesses (C and C_1) in the direction of the axes $o'z'$ and $o'y'$, construct similar figures in the parallel planes thus obtained. Now round and fillet the corner by constructing in isometry the arcs of the circles having the radii r_1 and r, respectively. To complete the bracket construct its upper portion which is in tangency with the lower piece, the tangent arc being specified by the radius r_2 (Fig. 198*a* and *c*).

The centres of the ovals for all the holes are found by the corresponding coordinates m, k, n, etc. indicated in Fig. 198*a*.

Erase all construction lines, except for the centre lines, and add surface shading (see Fig. 198*d*).

When finished in shading, axonometric projections of an object become more pictorial, as in Fig. 199.

When touching up the drawing by surface shading it is conventionally understood that the light falls on the subject obliquely from above.

Illuminated surfaces are finished with thinner lines spaced wider, shaded surfaces are indicated with thick, closely spaced lines.

Side surfaces of a pyramid or cone may be shaded with lines passing through their vertices. Spheric surfaces and surfaces of rotation are usually shaded with specific curved lines (say, concentric circles) of different thickness and spacing.

In addition, there are several other types of shading for geometrical solids. One of them is shown in Fig. 200. Illuminated areas gradually

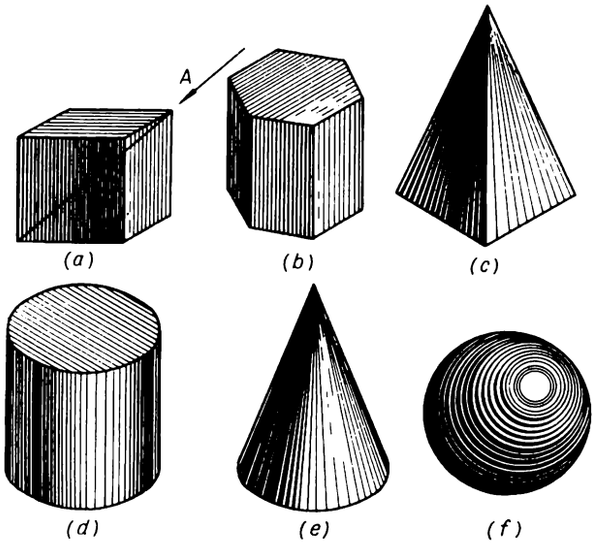


Fig. 199

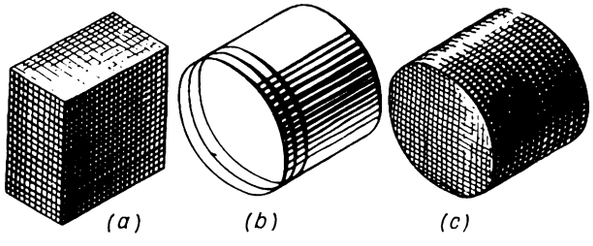


Fig. 200

merge into shaded surface, the shading lines becoming thicker. Besides, the contour lines nearer to the viewer are made thicker than distant outlines.

4. ORTHOGRAPHIC DIMETRIC PROJECTIONS

We have already mentioned orthographic dimetric projections of objects (see Fig. 183). With the orthographic projections of a cube given, we can construct both isometric and dimetric projections by utilizing the method of double revolution through different angles. First, the cube is revolved through 20° about the vertical axis (Fig. 201*a*). The second revolution is about the horizontal axis perpendicular to the plane *W*, also through an angle of 20°. The vertical projection of the cube obtained after the second revolution will be the orthographic dimetric projection (Fig. 201*b*).

The dimetric axes are constructed in the following way (see Fig. 183*a*): $o'z'$ is vertical; $o'x'$ is at an angle of 7° 10′ with the horizontal line, and $o'y'$ is at an angle of 41° 25′ with the horizontal line.

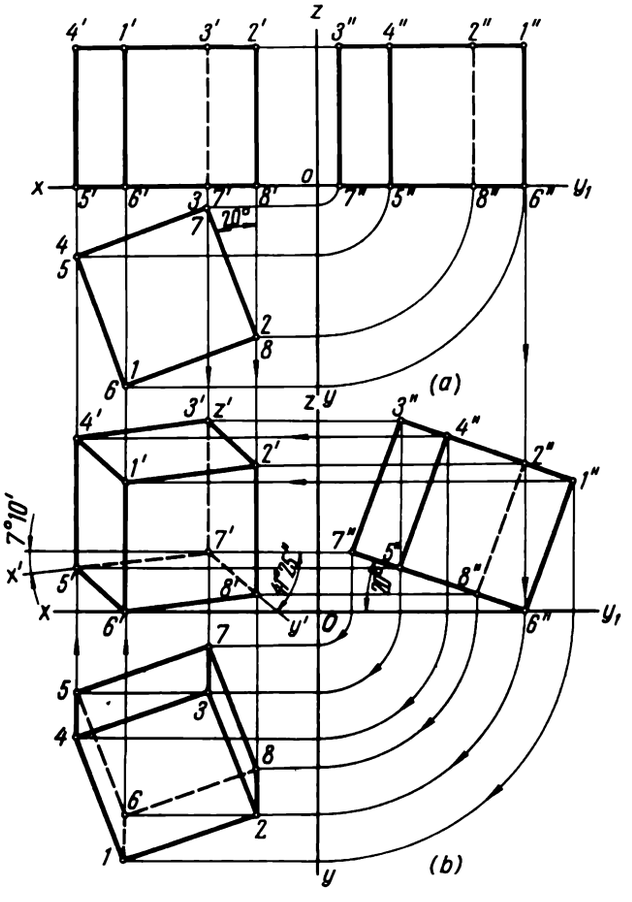


Fig. 201

All straight lines parallel to the axes *ox*, *oy*, *oz* in orthographic projections will retain their parallelism with respect to the like axes in dimetry. Line-segments drawn in the direction of the axes $o'z'$ and $o'x'$ are foreshortened to 0.94 of their true length, those in the direction of the axis $o'y'$ to 0.47.

For the sake of simplicity, the lines are usually not foreshortened in a dimetric drawing along the axes $o'z'$ and $o'x'$, but are halved along the axis $o'y'$.

An object may be placed in various positions relative to the dimetric axes (see Fig. 183*c*).

Fig. 202*c* illustrates the change of the height and base of a right hexahedral and a trihedral prism depending on the position of their faces with respect to the dimetric axes. If the edges are parallel to the axis $o'x'$, then the height is not changed, but the base becomes distorted. With the edges parallel to the axis $o'y'$, the height is reduced by one half. Similar changes occur in the other geometrical solids shown in the figure.

Hollow models must be given in a cut-away view (Fig. 202*b*).

The section is cross-hatched somewhat differently than in isometry. The length *a* is marked off along $o'z'$ and $o'x'$, and 0.5*a* along $o'y'$ (Fig. 202*a*).

Dimetric projections of geometrical solids and simple models are constructed with the aid of coordinates of some definitive points (say, vertices) in the same sequence as in isometry. First construct the base of the geometrical solid (for instance, the prism base — a triangle or hexagon, Fig. 202*c*). To simplify the construction, place the base parallel to one of the projection planes (or perpendicular to one of the axes). In this case certain coordinates of the points (vertices) will be the same or equal to zero. Then construct the edges and the base of the other solid.

Circles are represented in dimetry as ellipses* (Fig. 203). To construct a dimetry projection of a circle (an ellipse) contained in a plane paral-

* The major axis of ellipses, *AB*, is equal in all cases to 1.06*d*, where *d* is the diameter of the circle, the minor axis, *CD*, being equal to 0.35*d* when ellipses are located on parallelograms, and to 0.94*d* on rhombs.

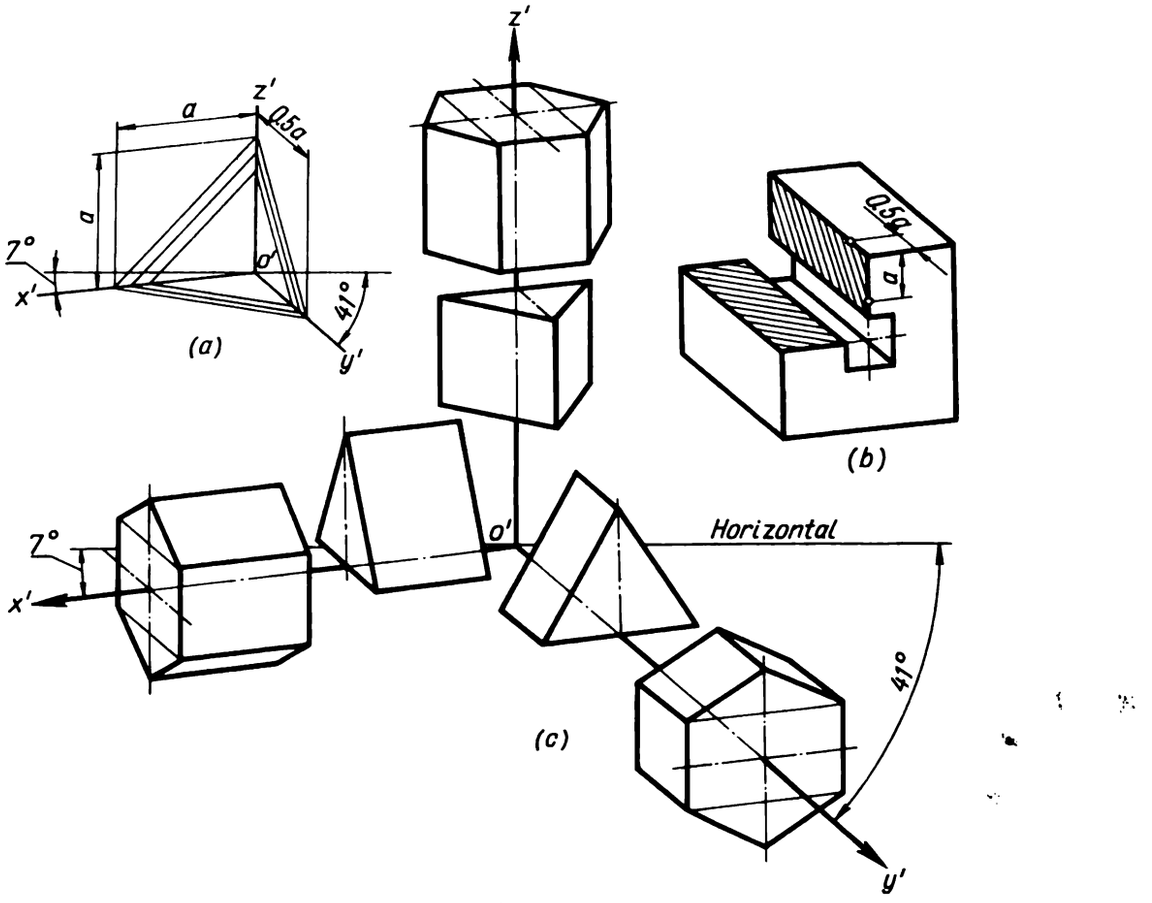


Fig. 202

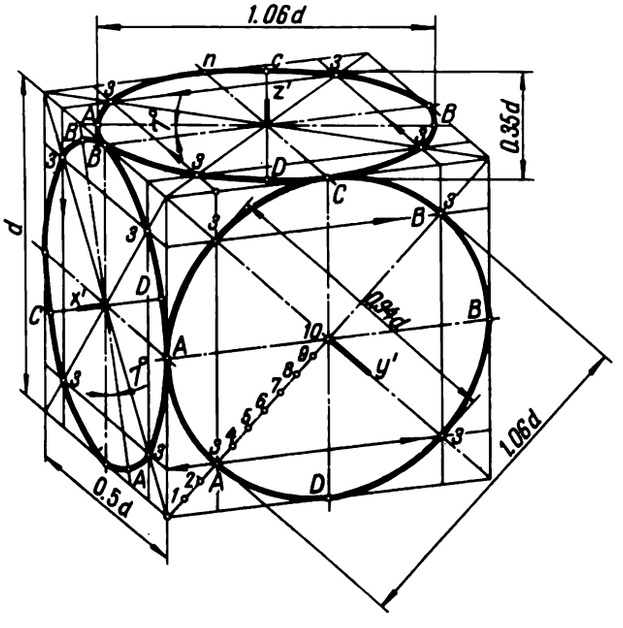


Fig. 203

lel to the axes $o'x'$, $o'z'$, divide half of the larger diagonal of the rhomb into 10 equal parts. Point *3* is on the required ellipse. Through this point draw two lines parallel to $o'x'$ and $o'z'$ to intersect the smaller diagonal at two points *(3)* which also belong to the required ellipse.

Then, draw straight lines in the directions indicated by the arrows and parallel to the axes to intersect all the diagonals, thus obtaining points *3* on all the three sides of the dimetric projection of the cube.

In addition to points *3*, there are four more points belonging to the required ellipse, namely, the points situated in the middle of the sides of the parallelograms (for instance, point *n*).

Through the points thus found draw smooth lines by means of a French curve to obtain the required ellipses.

Dimetric ellipses are sometimes replaced with ovals which are simpler to construct. This is illustrated in Fig. 204. Let us consider an exam-

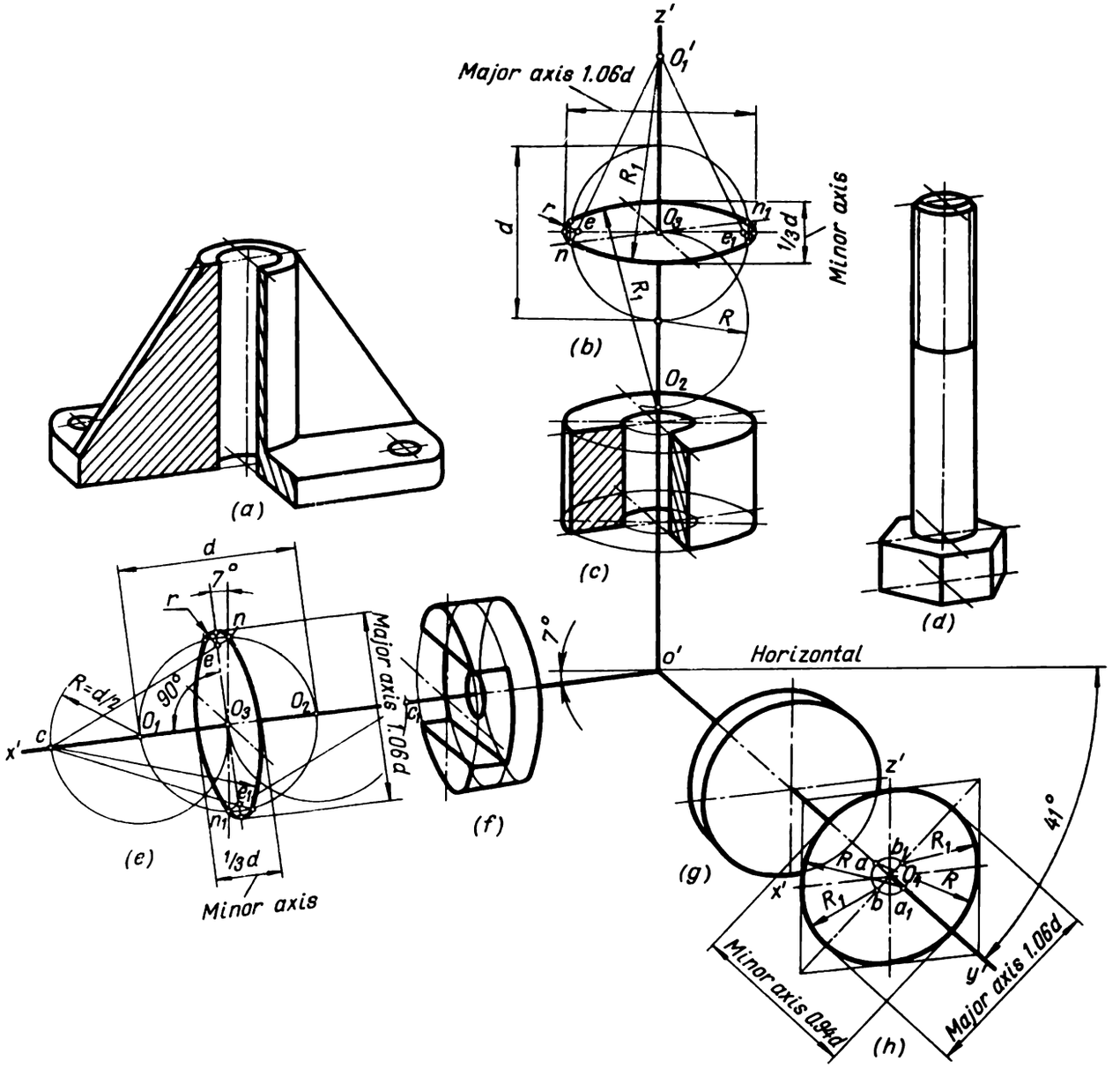


Fig. 204

ple of constructing the dimetric projection of a circle located on a plane perpendicular to the axis $o'y'$, that is parallel to the plane V (Fig. 204*h*).

Draw the axes o_4x' and o_4z' and mark off on them (from point o_4) lengths equal to $0.5d$. From o_4 as a centre describe an auxiliary circle of a diameter equal to $0.2d$. With b and b_1 as centres and with radius R_1 describe two arcs, and then from a and a_1 as centres and with radius R draw another two arcs to complete the required oval.

Now consider the construction of a circle contained in a plane perpendicular to the axis $o'x'$ (Fig. 204*e*).

From o_3 as a centre and with a radius equal to the radius R of the circle to be represented describe an auxiliary circle to intersect the vertical axis at points n and n_1 and the axis $o'x'$ at points o_1 and o_2.

From the points o_1 and o_2 and with radius R draw arcs to intersect the axis $o'x'$ at points c and c_1, and then from these points as centres

and with radius R_1 equal to the length cn describe two arcs. The points e and e_1 of intersection of the lines cn and c_1n_1, respectively, and the major axis of the oval, are the centres from which two tangent arcs of radius r are drawn to complete the required oval.

A dimetric projection of a threaded bolt is shown in Fig. 204*d*.

Begin the construction with drawing its axis which should be parallel to the dimetric axis $o'z'$. Then construct the hexagonal head of the bolt which is situated on a plane parallel to the plane H. The vertices of the hexagon are found from their coordinates. The edges of the head are drawn parallel to the axis $o'z'$. Now construct the body of the bolt which is a cylinder with oval bases. The thread is represented in a conventional way, i.e., by two thin lines.

A machine part with ribs is shown in Fig. 204*a*.

This is a hollow part cut by two planes passing through its axis of symmetry parallel to the projection planes V and W, respectively. First construct the rectangular base of the part with its sides parallel to the dimetric axes $o'x'$ and $o'y'$. The side parallel to the axis $o'y'$ is foreshortened to half its true length. Then construct a rectangular parallelepiped (the lower element of the part), whose shorter sides are parallel to the axis $o'z'$, and two concentric cylinders with the axis parallel to the axis $o'z'$ and oval bases. Finally, draw the ribs. It is more convenient to construct them from the coordinates z and x of their extreme points, laying off the thickness parallel to the axis $o'y'$. Do not forget to reduce the true thickness by one half.

Figure 205*a*, *b*, *c* presents the steps in constructing a stand in dimetry.

Here also, the part should be dismembered into simple geometrical elements, in this example into rectangular parallelepipeds of different heights with equal edges parallel to the axis $o'y'$ (Fig. 205*a*). Construct these adjacent parallelepipeds by marking off the edges parallel to the axes $o'z'$, $o'x'$, and $o'y'$. Do not forget to foreshorten along the $o'y'$ axis. Find the centres of the holes by using the method of coordinates, and construct some of the ellipses or ovals. Then construct the sections made by two cutting planes parallel to the planes V and W, respectively, to fully display the through cylindrical holes with vertical axes. Complete some ellipses and finish the projection with heavy contour

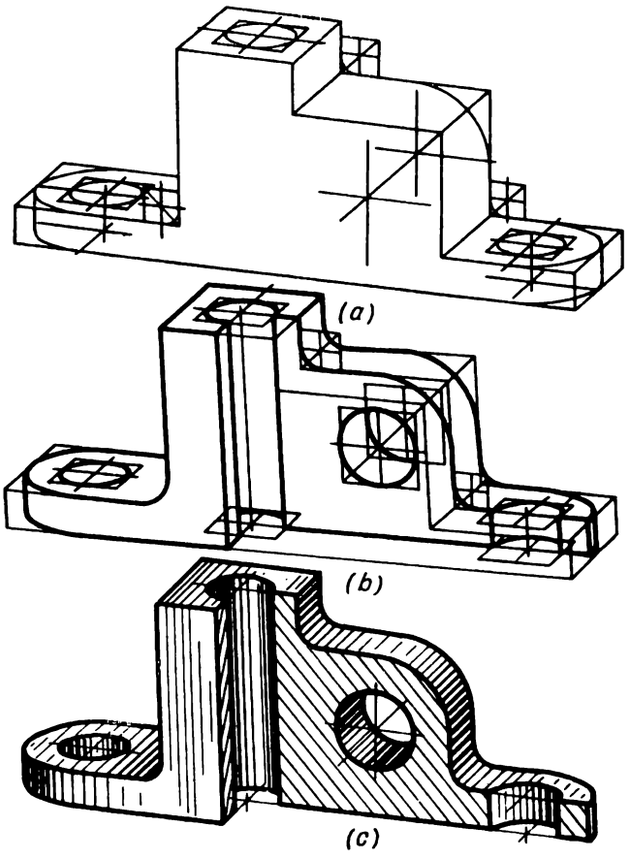


Fig. 205

lines (Fig. 205*b*). Cross-hatch the sections; clean up the drawing by removing the construction lines, and add a reasonable amount of shading.

In this example the mutual arrangement of the axonometric axes differs from that considered above and is permissible according to the USSR Standard.

In constructing geometrical solids and machine parts in dimetry, the object should be positioned so that its longer side is not parallel to the axis $o'y'$, as otherwise the dimetric representation will be strongly distorted.

5. FRONTAL DIMETRIC PROJECTIONS

The characteristic feature of frontal projections is that all lines and figures of an object, which were parallel to the vertical plane of projection, are represented in the vertical projection true size, that is without distortion.

The axonometric axes are arranged as follows: $o'x'$ is horizontal; $o'y'$ is directed at an angle of

45° to the horizontal and the actual dimensions of the lines parallel to this axis are halved; $o'z'$ is vertical (see Fig. 184). There is no foreshortening along $o'z'$ and $o'x'$, that is, the scale of projection is full size.

We may place an object in various positions with respect to the axes (see Fig. 184*c*), but it should be borne in mind that it is preferable to place it so as to bring its complicated plane figures, circles, arcs of plane curves into coincidence with planes parallel to the vertical plane of projection. Then the construction is simplified, since they are projected true size.

Of the positions of the cylinder shown in Fig. 206*a* and *c* the latter is preferable, since the circles are not distorted.

Another example of rational arrangement of a machine part is presented in Fig. 207: the circles of the cylindrical portion of the bearing and the bore are contained in a plane parallel to the plane *V*.

Frontal projections of geometrical solids are constructed similarly to isometric.

Construct a frontal projection of a cylinder (Fig. 206*a*). First draw the base, which is an ellipse, then the extreme elements. Remember that all the straight lines directed parallel to the axes of projection retain their parallelism to the like axes in frontal projection. To complete the cylinder, draw its second base.

Ellipses may be replaced with ovals, whose construction was discussed in detail under di-

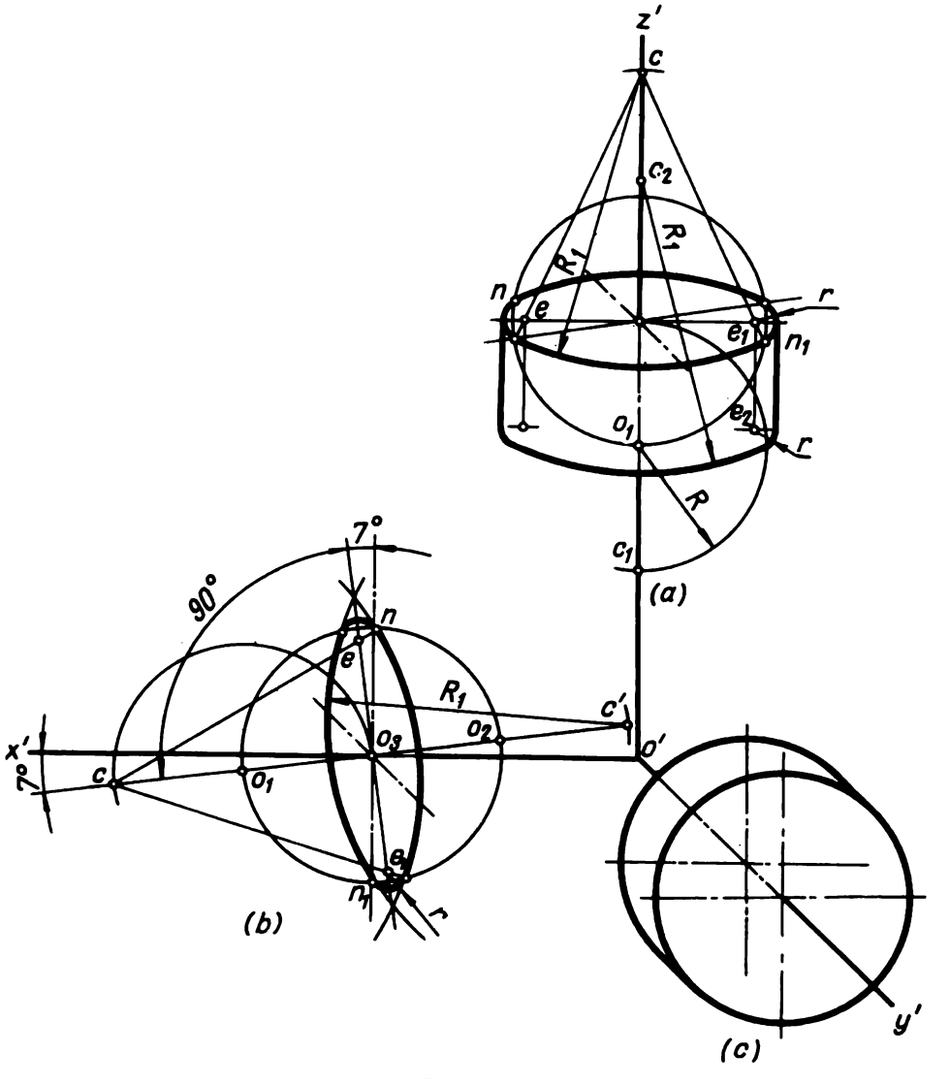


Fig. 206

metric projections and is shown in Fig. 206*a* and *b*.

In drawing the second base of the cylinder you should not repeat the construction of the oval. It is sufficient to find the position of the centre c_2 of the larger arc of the required oval by marking off to the right (or downwards) of point *c* a length equal to the height of the cylinder. From c_2 as a centre and with radius R_1 draw the larger arc of the oval. With e_1 as a centre and with radius *r* describe the tangent arc (Fig. 206*b*). The distance between the points e_1 and e_2 is equal to the height of the cylinder *h* (Fig. 206*a*).

In constructing frontal projections it is advisable to use a 45°-45° triangle (Fig. 207).

Cross-hatching of sections in frontal projections is shown in Fig. 208*a* and *b*. The slant is found by laying off along the axes *o'x'* and *o'z'* any line-segments of equal length *a* and segments equal to 0.5*a* along the axis *o'y'*.

Hollow parts should be given in sectional views, the sections lying in the cutting planes are cross-hatched.

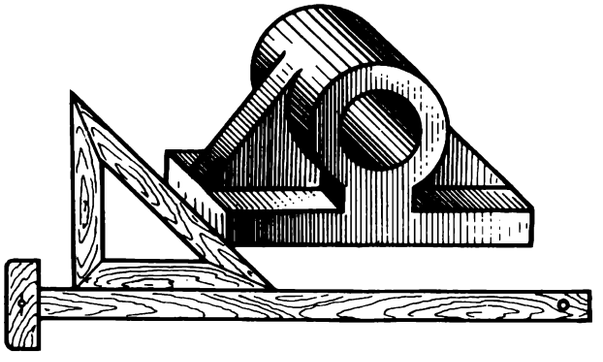


Fig. 207

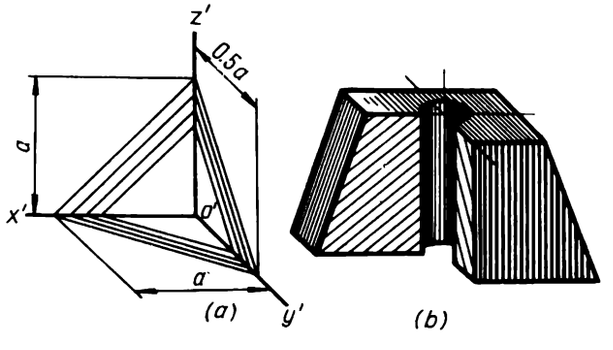


Fig. 208

Fig. 209 indicates the steps in constructing a frontal projection of a crosspiece.

Extension and dimension lines are drawn parallel to the axonometric axes.

Questions

1. What kinds of axonometric projections are used in engineering and what is the difference between them?
2. What angles with the horizontal do the axonometric axes make in isometric, dimetric and oblique frontal projection?
3. How are ellipses constructed in rectangular isometric and dimetric projections to represent circles lying in planes parallel to the projection planes?
4. How is a plane curve of an arbitrary type

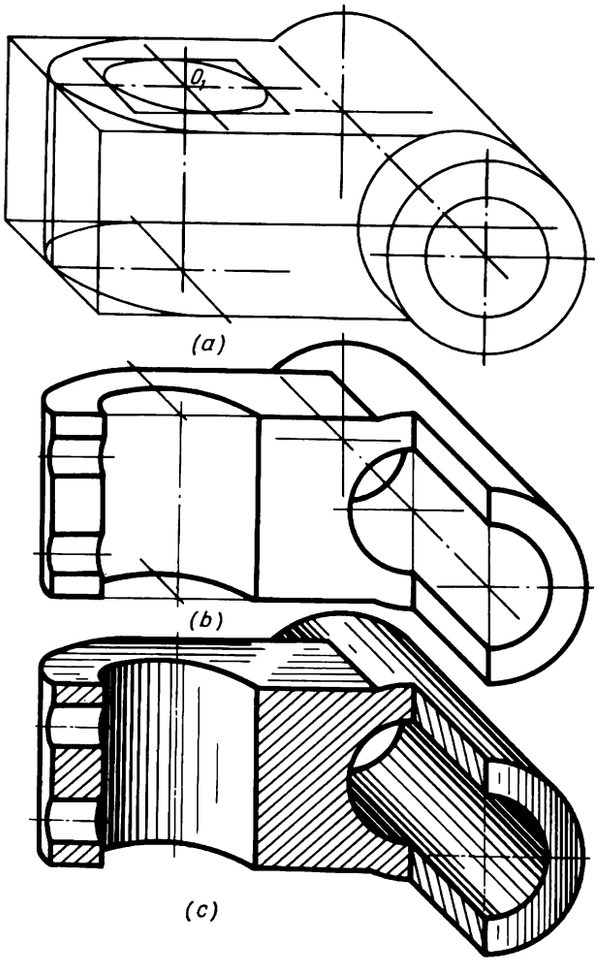


Fig. 209

constructed in isometry with its orthographic projections given?

5. How should a circle be arranged in constructing its oblique frontal projection?

6. Along which dimetric axis is it inadvisable to arrange a long object?

7. How are axonometric sections made and what is the direction of the cross-hatching lines?

8. How are ovals replacing ellipses constructed in isometry and dimetry?

9. In what directions are dimension lines drawn in axonometric projections?

Exercise 39

Make isometric projections of the models shown in Fig. 189*b*, *c*, *e* to a scale 2/1 (twice full size).

Exercise 40

Make isometric projections of the models shown in Fig. 193*c*, *e*, *f* to a scale 2/1.

Exercise 41

Make a dimetric projection of the model shown in Fig. 202*b* to a scale 2/1.

Exercise 42

Make a dimetric projection of the model shown in Fig. 204*c* and *f* to a scale 2/1.

Exercise 43

Make a frontal projection of the model shown in Fig. 209*c* to a scale 1/1 (full size).

CHAPTER 7

TECHNICAL SKETCHING

1. SKETCHING STRAIGHT LINES, PLANE FIGURES AND GEOMETRICAL SOLIDS

In designing machines the engineer often has to rapidly draw pictorial views of machine parts so as to render their shape with sufficient clarity. The process of making such freehand pictures is called *technical sketching*.

To acquire skill in pictorial sketching it is advisable to begin with straight lines and angles, dividing them into equal parts. The next step is sketching plane figures: polygons, circles, and ellipses followed by geometrical solids, and, finally, mastering the technique of sketching machine parts and assemblies.

Geometrical solids and machine parts should first be sketched from a model. The final stage is sketching of simple machine parts from their drawings.

A technical sketch is usually made in *isometric* (Fig. 210*a*), *frontal* (Fig. 210*b*) or *dimetric projection*.

Sketches in perspective (central projection) are seldom used in mechanical engineering, because they are difficult to construct and introduce substantial distortions (Fig. 210*c*).

Exercises in drawing straight lines freehand

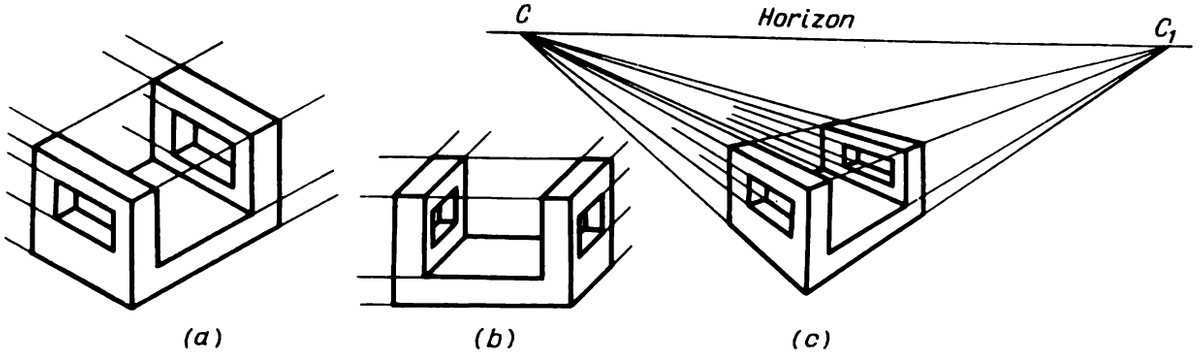


Fig. 210

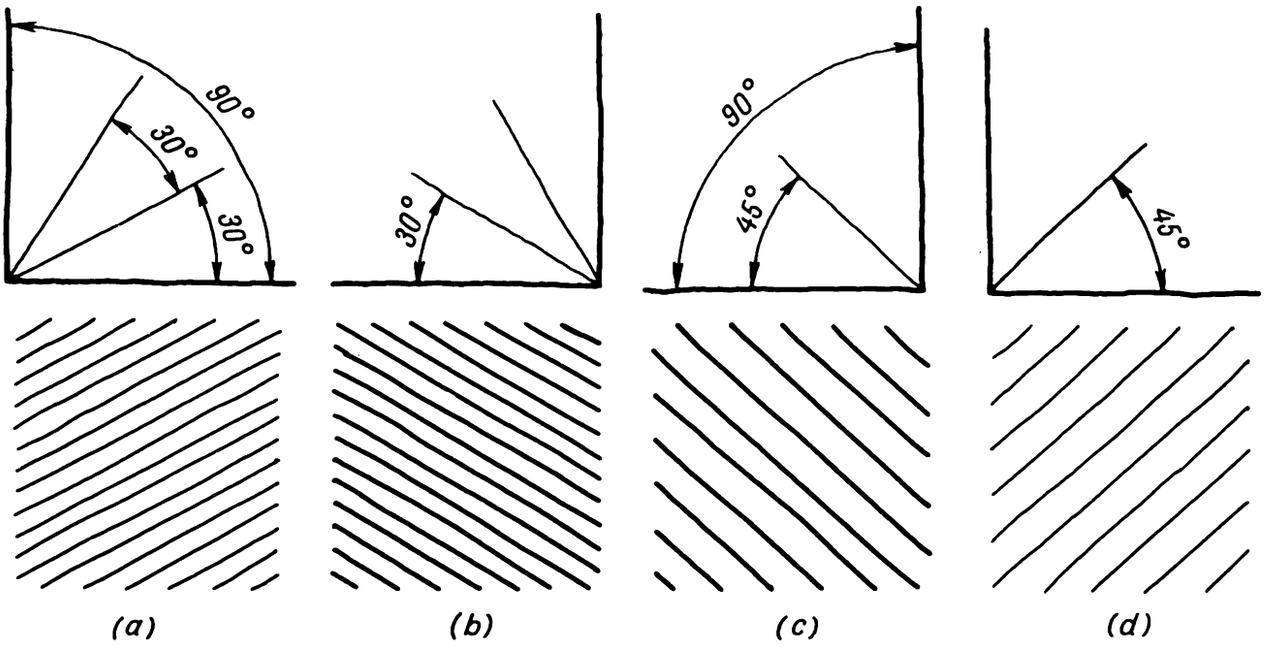


Fig. 211

are usually done on plain unruled paper using a soft pencil. The pencil should be held freely. Vertical lines are drawn downward with a finger movement in a series of short overlapping strokes, while horizontal lines are sketched using a wrist motion for short lines and forearm motion for longer ones. In drawing any straight line between two points, keep the eyes on the point to which the line is being drawn rather than on the point of the pencil. Do not try to draw the whole length of a line in a single stroke. First draw a very light line, then sketch the finished line correcting the direction of the light line without erasing it. Do not be disturbed by waviness. Accuracy of direction is more important than smoothness of the line.

Steep lines running downward from right to left are drawn easily with the same movement as vertical lines, but those running downward from left to right are much harder to draw (except for left-handed persons); therefore it is advisable to turn the paper and draw them as horizontal lines. The three important things about a straight line are: (1) that it be essentially straight; (2) that it be the right length, and (3) that it go in the right direction.

Practise sketching lines several times until a straight line is obtained at the first stroke.

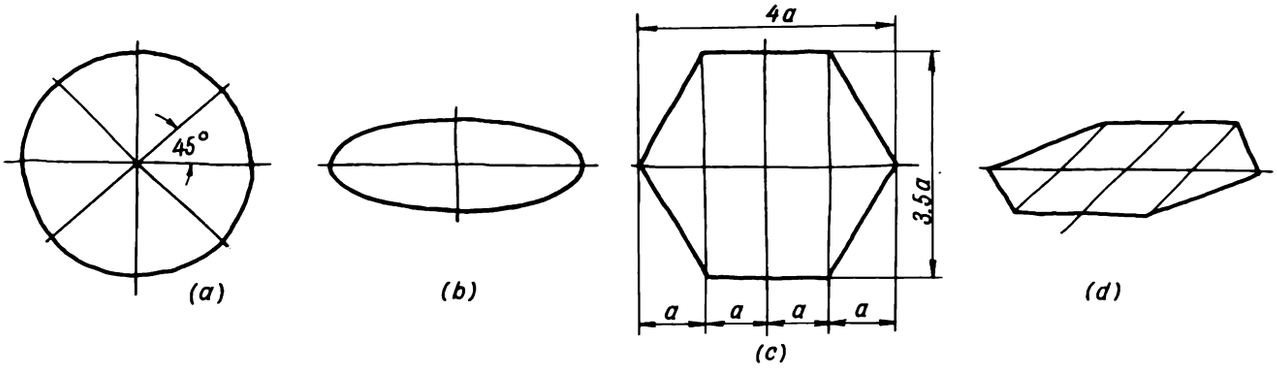


Fig. 212

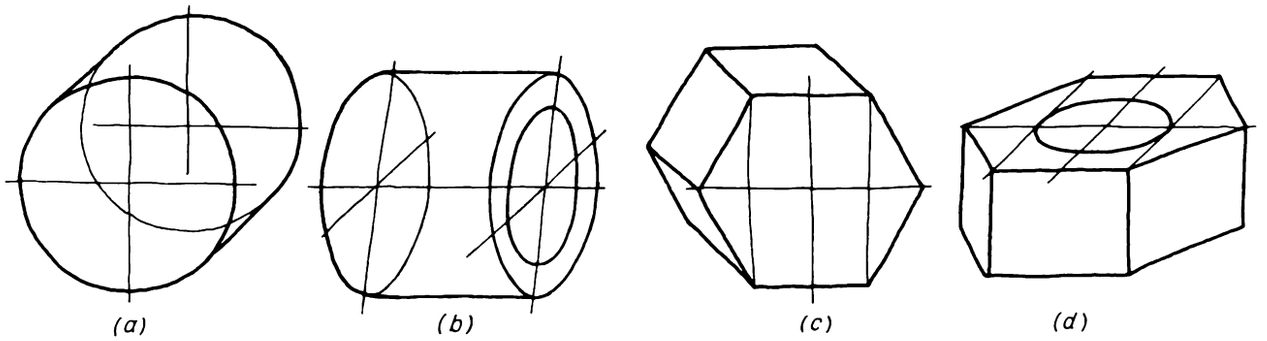


Fig. 213

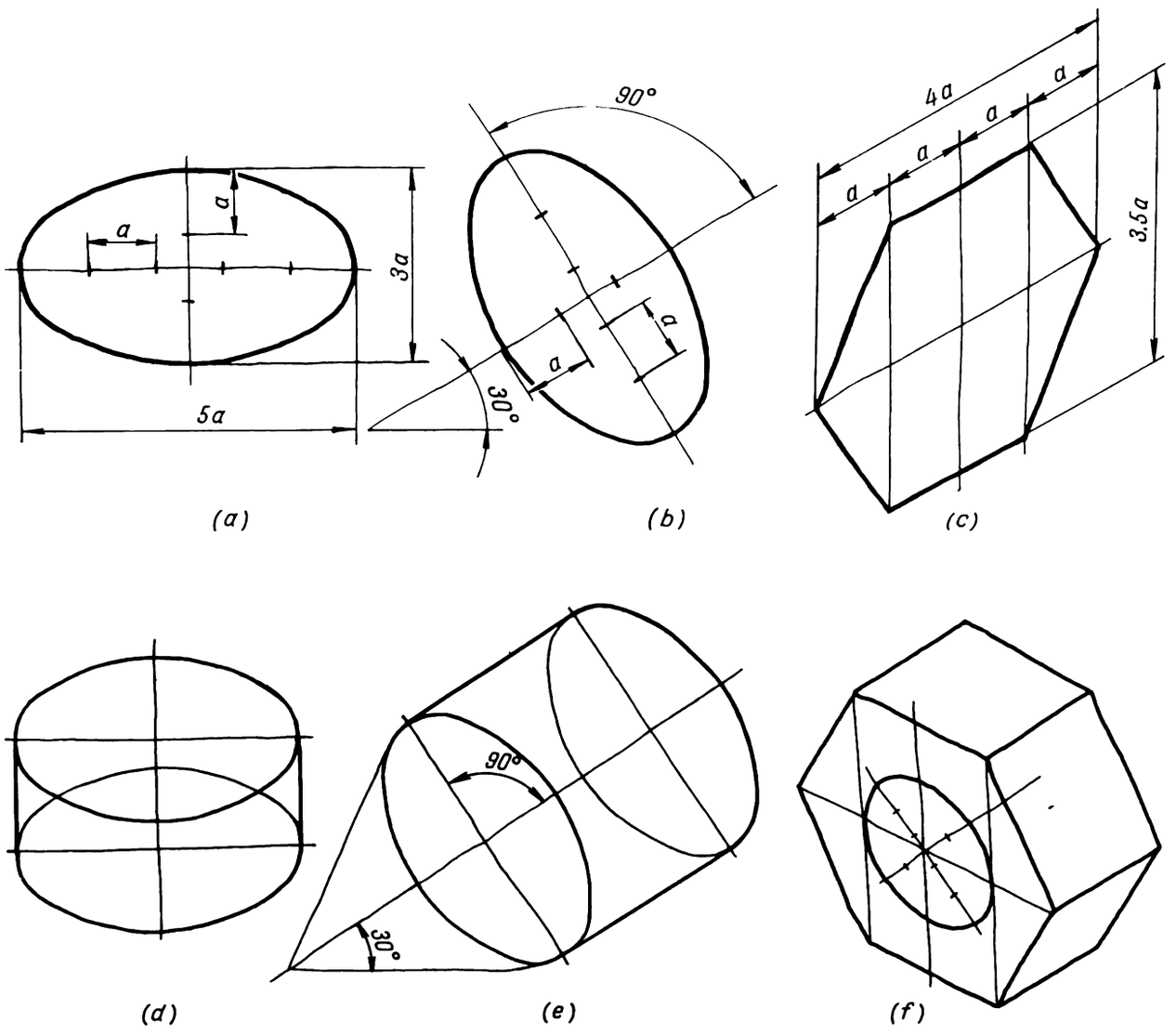


Fig. 214

It is of utmost importance to acquire the skill of rapid and accurate sketching of straight lines at angles of 30° and 45° with the horizontal, since such inclined lines are often used in isometric and frontal projections.

The construction of angles and drawing of parallel lines without the aid of drawing instruments are shown in Fig. 211.

Circles and ellipses. A circle may be drawn by first marking two mutually perpendicular axes (vertical and horizontal), then drawing another pair of mutually perpendicular lines at an angle of 45° to the horizontal, and laying off the required radius on the eight lines thus obtained (Fig. 212*a*). Draw short arcs, then complete the circle, first with a light line. After checking and correcting faults finish the circle with a heavier line. An ellipse is drawn freehand after the axes are constructed (Fig. 212*b*).

Plane figures, such as a regular hexagon (Fig. 212*c*), are frequently encountered in sketching nuts and other parts. Here, too, begin with drawing a vertical and a horizontal line of symmetry. Lay off four equal lengths *a* on the horizontal line and a length of approximately 3.5*a* on the vertical line, thus marking the vertices and sides of the required hexagon. Then complete the figure.

The construction of the same hexagon in the horizontal plane of projection is shown in Fig. 212*d*. As is obvious from the drawing, the dimensions of the hexagon are foreshortened along the axis *oy*.

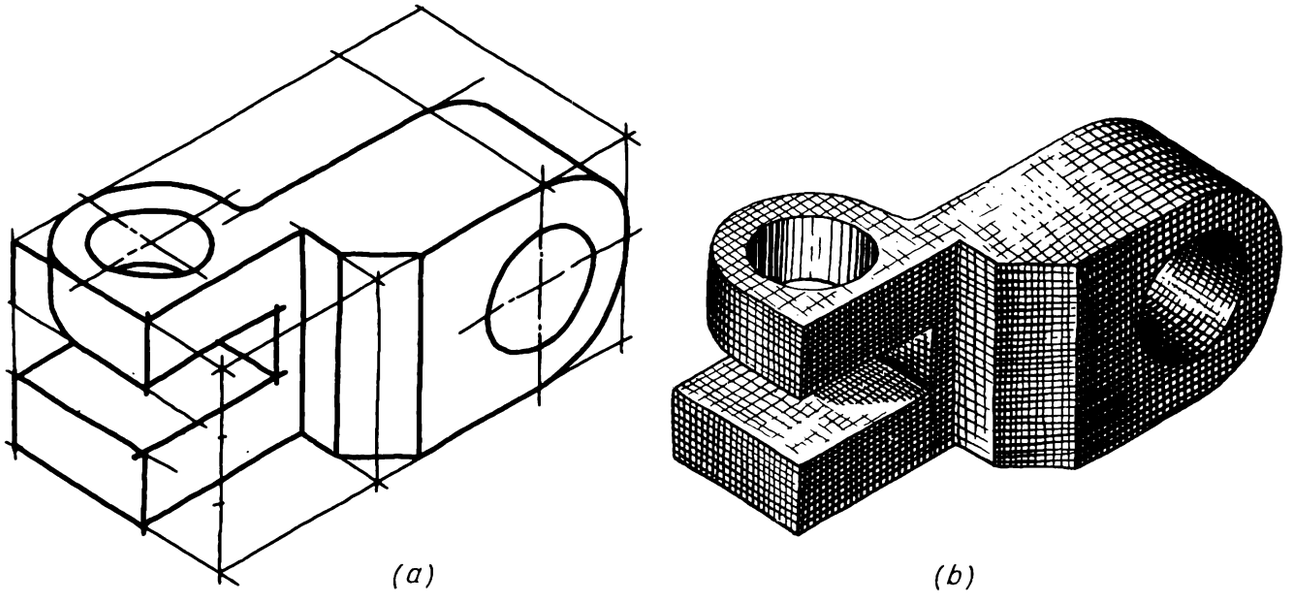
Having done a number of exercises in sketching plane figures we can proceed to sketching geometrical solids.

Fig. 213 illustrates the use of methods of drawing circles, ellipses and hexagons in sketching various geometrical solids.

Special attention should be paid to the methods of sketching ellipses in isometry. If an ellipse represents a circle contained in a horizontal plane (Fig. 214*a*), then it is drawn freehand by making use of the lengths of the axes. Shown in the figure is an ellipse with a 5:3 ratio of the major to the minor axis.

If an ellipse is situated in a profile plane (Fig. 214*b*), first draw the minor axis by eye at an angle of 30° to the horizontal and then the major axis perpendicular to the minor axis. Mark off on the axes the appropriate number of lengths *a* in the ratio 5:3 and complete the ellipse.

In sketching a regular hexagon (Fig. 214*c*) also begin with drawing the axes of symmetry. On an axis drawn at an angle of 30° to the horizontal mark off four equal lengths *a* and a length of about 3.5*a* on the vertical axis. The points thus obtained determine the vertices and sides of the required hexagon. Shown in Fig. 214*d* and *e* are technical sketches of two cylinders, whose bases are ellipses. Fig. 214*f* illustrates a sketch of a blank for a hexagonal nut.



(*a*) (*b*)

Fig. 215

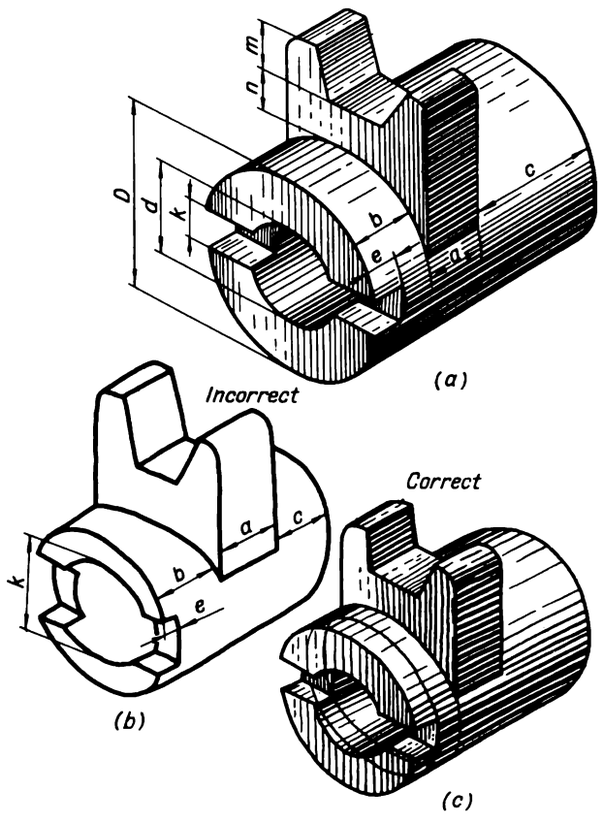


Fig. 216

2. SKETCHING MACHINE PARTS

When making a technical sketch of a machine part begin with constructing its overall outlines (the so-called "dimension cage") in light lines. In our example (Fig. 215*a*) such a dimension cage is a rectangular parallelepiped. Since any machine part may be thought of as consisting of separate elements which resemble some geometrical solids, sketch all elements step by step until the whole machine part is obtained. Finish the sketch by adding surface shading, as in Fig. 215*b*.

When sketching a machine part from a model (for example, a cam, as in Fig. 216*a*) the student, while carefully scrutinizing its shape, must also compare the size of its separate elements, thus developing his sense of proportionality. Presented in Fig. 216 are two technical sketches made from one and the same model. It is quite obvious that the sketch in Fig. 216*b* is incorrect, since proportionality is not observed. The distance *b* is not uniform and therefore the line of intersection (a portion of an ellipse) of the flat lug with the cylinder is incorrect. As compared with the model, dimension *k* is considerably enlarged, the thickness of the cylinder wall is reduced, as is the depth of the slot *e*. The dimension *c* must be approximately 2.5 times larger than *a*, while in Fig. 216*b* they are equal. Fig. 216*c* gives a correct version of the sketch.

The interior of a machine part is usually shown with the aid of sections. The methods of making sections are considered under axonometric projections (see Figs. 189-209).

The making of pictorial sketches from orthographic drawings provides excellent practice in reading drawings.

Questions

1. How are freehand lines drawn on a technical sketch at an angle of 30° and 45° with the horizontal?
2. How is a right angle divided into three equal parts on a technical sketch?
3. What are the methods of freehand construction of ovals and regular hexagons on a technical sketch?
4. What is the difference between surface shading and cross-hatching?

Exercise 44

Draw several straight lines (freehand, with a soft pencil) at angles of 30°, 60°, and 45° to the horizontal as in Fig. 211.

Exercise 45

Sketch a series of circles and ellipses in various positions relative to the axonometric axes as in Figs. 212 and 213.

Exercise 46

Make sketches of a cylinder, prism and pyramid from models.

Exercise 47

Make sketches of two or three simple models and machine parts. Add surface shading as in Fig. 197*a* and *b*.

CHAPTER 8

PROJECTIONS OF GEOMETRICAL SOLIDS

In making drawings of machine parts most frequently we have to deal with the following geometrical solids (Fig. 217): prisms, pyramids, cylinders, cones, spheres, and solids of revolution (for instance, a ring or torus).

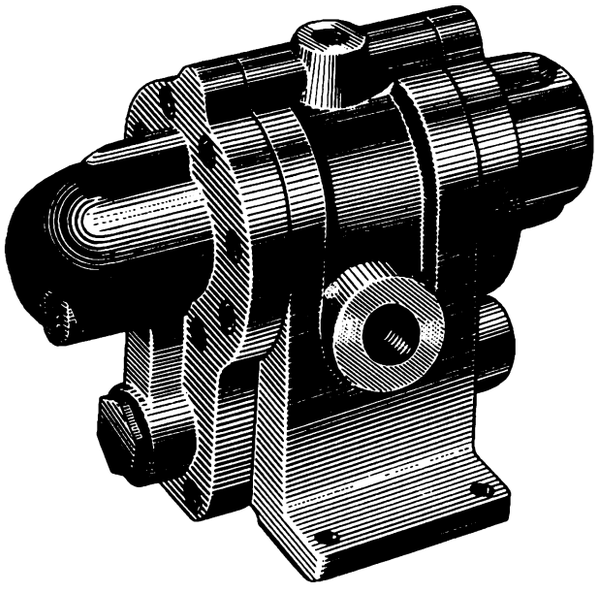


Fig. 217

The pyramid and prism are bounded by plane figures called faces and that is why they are termed polyhedrons. The rest of the geometrical solids are bounded by curved surfaces and plane figures (bases) and have surfaces generated by a line revolving about an axis. The cylinder, cone, sphere, ring, and torus are solids of revolution.

1. PROJECTING A CYLINDER

The simplest thing is to construct the orthographic projections of a right circular cylinder having a vertical axis. Its side surface is formed by a generatrix *AB* moving about its axis along the base circle which serves as the directrix. Fig. 218*a* presents a cylinder, Fig. 218*b* and *c* shows the steps in making its two projections: horizontal and vertical.

To simplify the construction, the base should be arranged parallel to the plane *H*.

Begin the construction with the base, i.e., by drawing two projections of a circle (Fig. 218*b*). Since the circle is situated parallel to the plane *H*, its horizontal projection will be a circle, its vertical projection being a straight line equal in length to the diameter of the circle. Then on

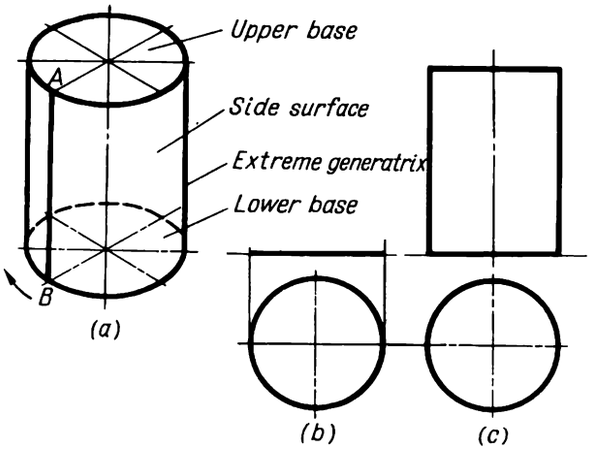


Fig. 218

the vertical plane draw two extreme elements and lay off the height of the cylinder on them.

Draw a horizontal line which will be the vertical projection of the upper base of the cylinder. The horizontal projections of the upper and lower bases coincide.

2. PROJECTING A CONE

Fig. 219*a* presents a right circular cone. Its side surface is generated by the generatrix *BS* moving about the cone axis along the base circle. Fig. 219*b* and *c* shows the steps in making the horizontal and vertical projections of the cone.

First construct the two projections of the base. Its horizontal projection is a circle; if the base is contained in a plane parallel to the plane *H*, then its vertical projection will be a line-segment equal to the diameter of this circle. To complete the vertical projection of the cone erect a perpendicular at the middle of the base and mark off the height of the cone on it (Fig. 219*c*). Join the point thus obtained (which is the vertical projection of the vertex) with the base by straight lines.

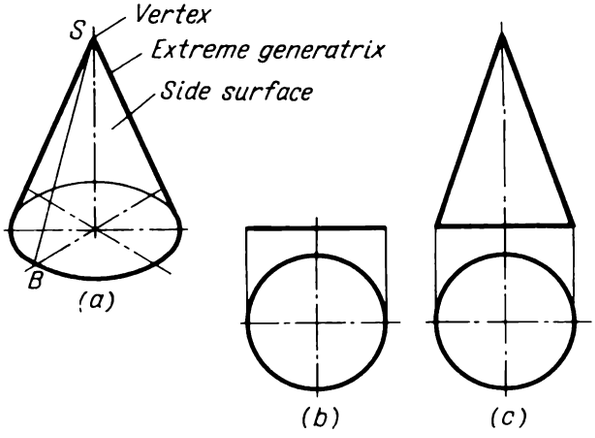


Fig. 219

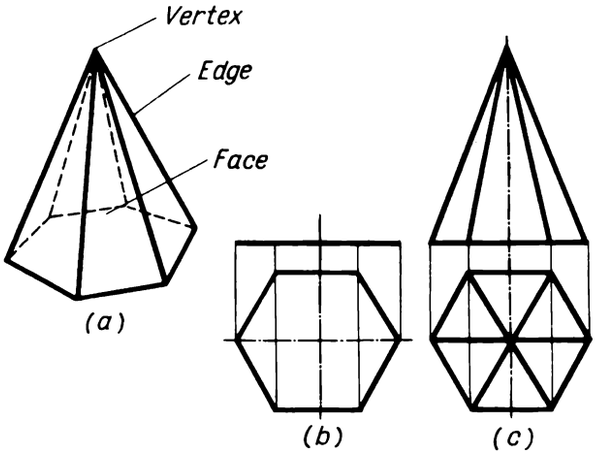


Fig. 220

3. PROJECTING A PYRAMID

Begin the construction of two projections of a right regular pyramid (Fig. 220*a*) by projecting its base, a regular hexagon (Fig. 220*b*). As is known from geometrical drawing, it can easily be constructed with the aid of a compass or a 30°-60° triangle.

Then draw vertical projecting lines for all the vertices of the hexagon.

Erect a perpendicular at the middle of the vertical projection of the base and mark off the height of the pyramid. Join the point thus obtained to the vertices of the hexagon by straight lines which are the vertical projections of the side edges. As is seen from Fig. 220*c*, the vertical projections of the two front edges and the two rear edges coincide. The horizontal projections of all six side edges are obtained by joining the horizontal projection of the vertex of the pyramid with the horizontal projections of the six vertices of the base.

4. PROJECTING A PRISM

It is quite easy to construct the projections of a right regular hexagonal prism (Fig. 221). First construct the horizontal projection of the prism by drawing a regular hexagon and then the vertical projection, on which four vertical edges are represented. The horizontal projections of the upper and lower bases coincide; the vertical projections of the two front edges and the two rear edges also coincide.

It is more difficult to construct two projections of an inclined prism.

Consider the sequence of constructing the orthographic projections of a hexagonal prism inclined to the plane *H*. Two cases are possible here:

(1) *An oblique prism is inclined at an angle* α *to the plane H* (Fig. 222). Its side edges are parallel to the plane *V*, i.e., they are frontal lines.

Begin the construction with the base of the prism, assuming that the lower base (which is a regular hexagon) is situated on the plane *H*.

In this case the horizontal projection will be the true size of the hexagon. It is very simple to construct a regular hexagon with the aid of a

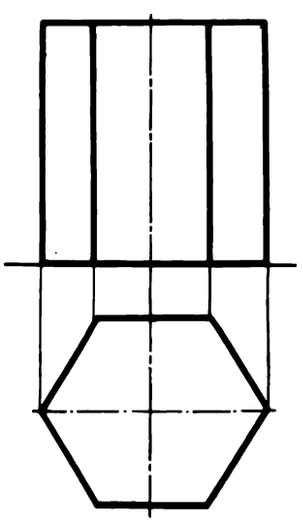


Fig. 221

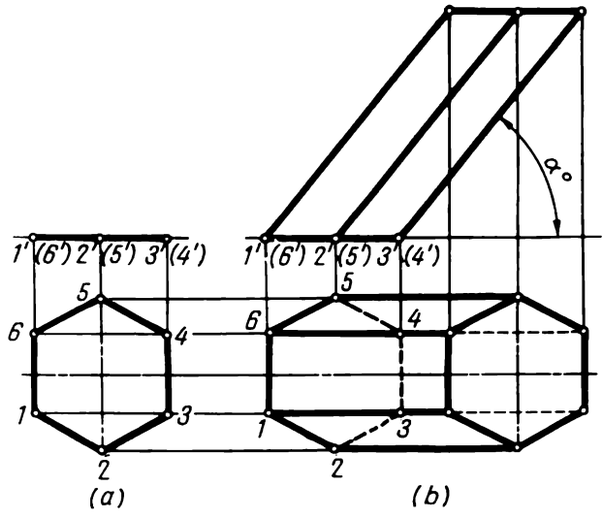


Fig. 222

compass. The vertical projection of the base coincides with the *ox* axis.

From the vertices of the hexagon (points *1* through *6*) on the vertical projection draw straight lines (edges) at an angle α with the horizontal and mark off on them the true length of the edges (Fig. 222*b*). In this and other figures the coinciding like projections of the points are designated differently. For instance, the vertical projections of points *2* and *5* are designated as *2'* and (*5'*), i.e., the projection of point *5*, which is closer to the plane *V*, is denoted by a figure in brackets.

Now construct the vertical projection of the upper base which will be parallel and equal to the projection of the lower base. The horizontal projection of the upper base is a hexagon identical to that of the lower base.

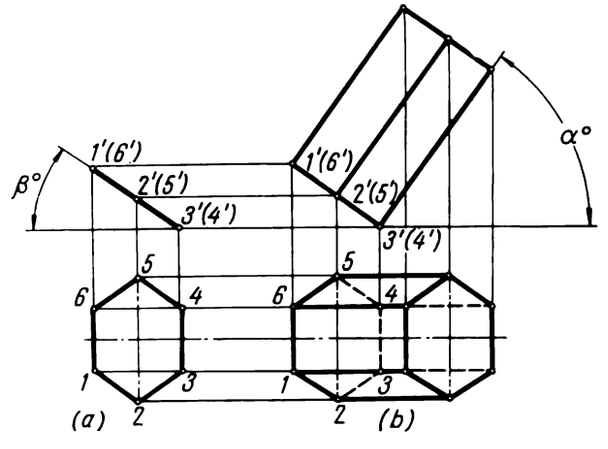


Fig. 223

Through points *1-6* of the hexagon on the horizontal projection draw straight lines (edges) parallel to the axis *ox* and on them project vertically the six points, the vertices of the upper base of the prism.

(2) *A right regular prism is inclined at an angle α to the plane H* (Fig. 223). Its base, a regular hexagon, makes an angle $\beta=90°-\alpha$ with the plane *H*.

Here we must begin the construction with the vertical projection of the lower base which will be a line-segment of the true length equal to the distance between a pair of parallel sides of the hexagon. Bisect this line and from its midpoint drop a perpendicular onto the axis *ox*. Vertices *2* and *5* of the base will lie on the extension of this perpendicular, the distance between them being equal to the true distance between the respective vertices of the base. Since the length of sides *1-6* and *3-4* on the plane *H* will be the true length, we are in a position to complete the horizontal projection of the base. The further procedure is the same as in Fig. 222. The vertical projections of the vertices of the lower base are denoted as above.

5. PROJECTING A SPHERE

Fig. 224*a* is a pictorial representation of a hemisphere whose surface is generated by the circular arc *AB* moving about the axis *AO* along the guiding base circle, or equator.

The projections of the hemisphere are shown in Fig. 224*b*. The horizontal projection is a circle

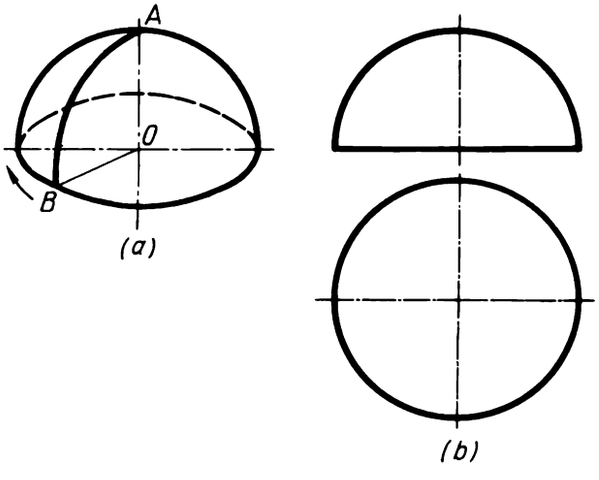


Fig. 224

whose radius is equal to that of the sphere, the vertical projection being a semi-circumference of the same radius.

6. PROJECTING A RING AND A TORUS

Fig. 225*a* shows a circular ring whose surface in generated by the circle *ABCD* revolving about the axis *OO* along the guiding circle of radius *R*.

The horizontal projection of a circular ring or an open torus represents two concentric circles, the difference of their radii being equal to the thickness of the ring or to the diameter

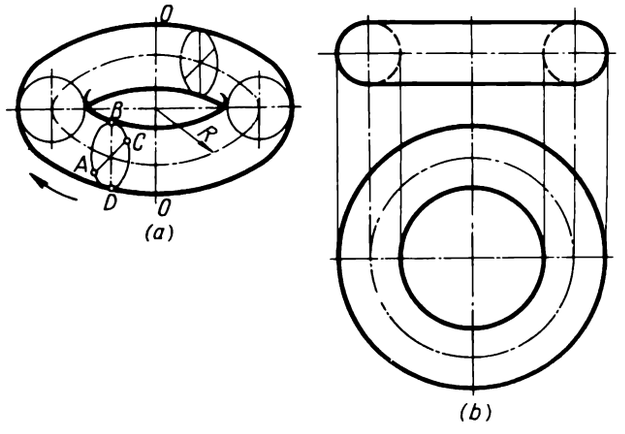


Fig. 225

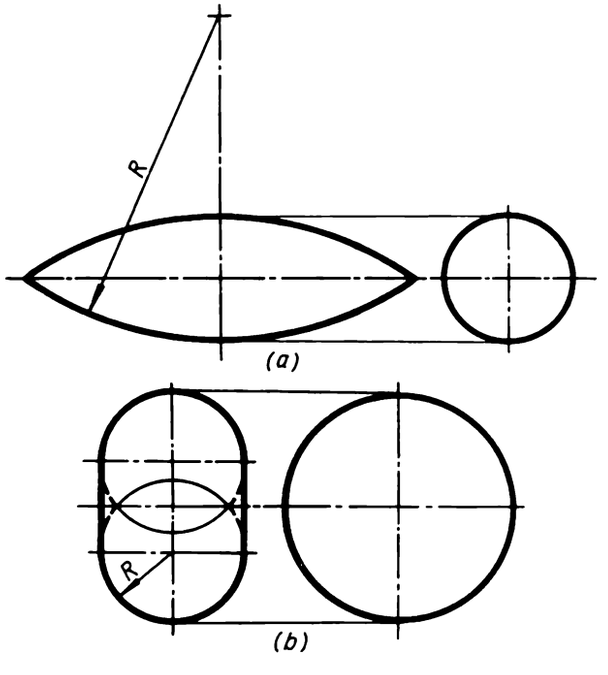


Fig. 226

of the generating circle (see Fig. 225*b*). The vertical projection is bounded on both sides by semi-circumferences of the generating circle.

The torus is a surface generated by an arc revolving about any axis in its plane other than its diameter. Shown in Fig. 226 are two kinds of torus. The first torus (Fig. 226*a*) is generated by an arc (of radius *R*) which is less than a semi-circumference, the second by an arc whose length is more than half the circle. In both cases the vertical projection represents the true image of the two generating arcs of radius *R* located symmetrically relative to the vertical projection of the axis of revolution. The profile projection of the torus is a circle.

7. GEOMETRICAL SOLIDS AS ELEMENTS OF MACHINE PARTS

Geometrical solids may be solid or hollow, i.e., with holes, recesses, etc., which are also bounded by various geometrical surfaces. The boundaries of these surfaces are usually drawn as invisible contours, i.e., in dashed lines. An example of pictorial representation of a geometrical solid in space is given in Fig. 227*a*. Shown in the figure is a right trihedral prism with a through cylindrical hole, and Fig. 227*b* shows three orthographic projections of the prism.

Begin the construction with the vertical projection on which the two bases of the prism coincide and are projected true size as an equilateral triangle. The base of the cylindrical hole is also projected in true size as a circle.

Then construct the horizontal and profile projections of the prism. On them the extreme elements of the internal cylinder must be shown as invisible contours, that is, drawn as a dashed line.

There is a boundless variety of machines whose elements are rich in shapes containing the foregoing geometrical solids.

Fig. 228*a* shows a bush with a bead. It is a hollow solid bounded by two cylindrical surfaces on the outside and by one cylindrical surface on the inside. Presented in Fig. 228*c* is a plug gauge designed for gauging holes. Its handle has the shape of a right hexahedral prism with a cylindrical hole. Fig. 228*b* illustrates a jack whose stand is a hollow geometrical solid bounded by a taper (middle), cylinder (top), and a prism (bottom).

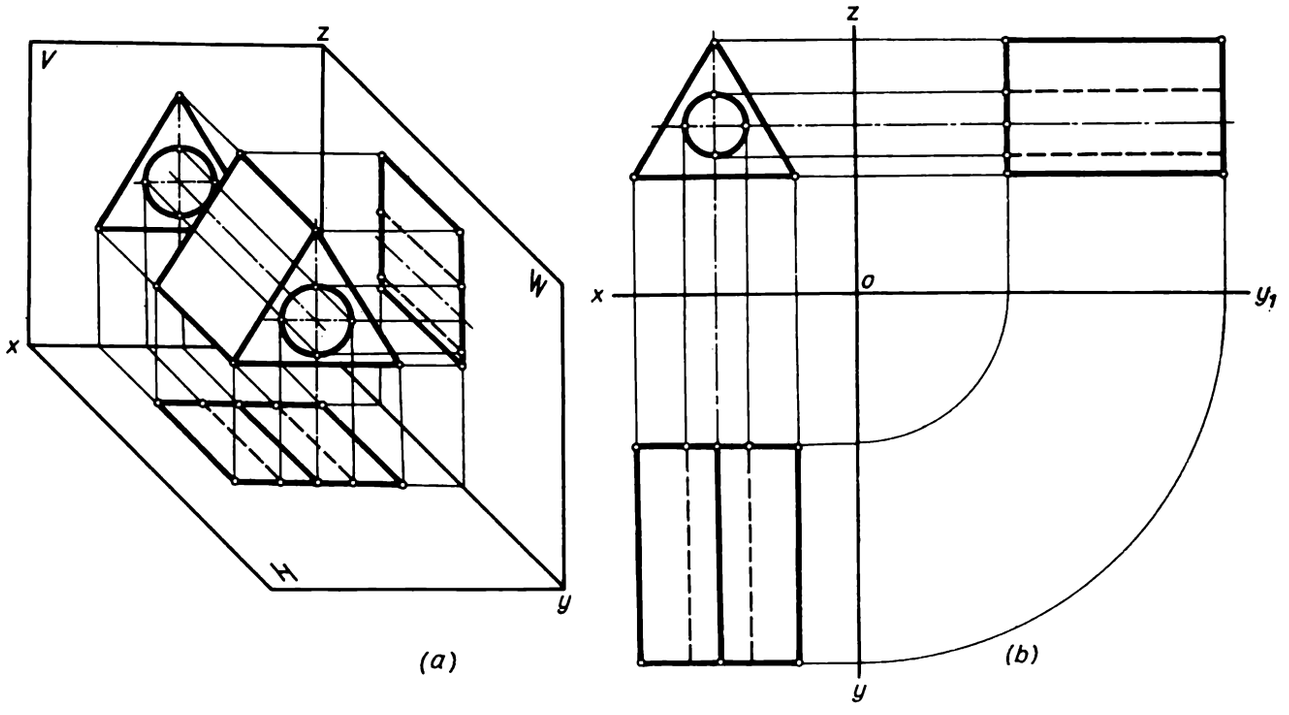


Fig. 227

Another example of a hollow machine part is the base of a grinding machine (see Fig. 228*d*) which is bounded by the surface of a tetrahedral truncated pyramid both on the outside and inside.

In all the foregoing cases the geometrical solids had cavities and recesses of comparatively simple shapes and it was not so difficult to construct their projections. Machine designers often have to deal with complicated cavities and recesses. To construct their projections one has to be familiar with some additional constructions, such as:

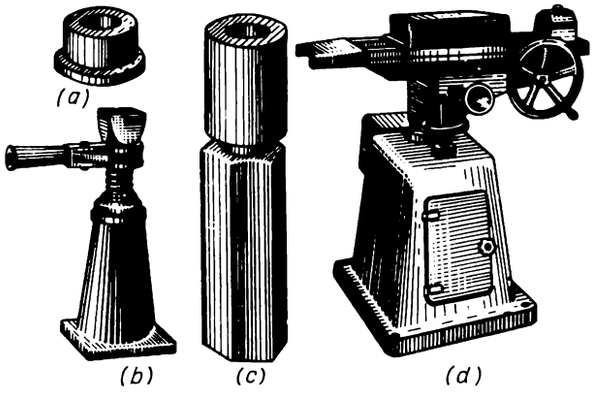


Fig. 228

(1) to construct two other projections of a random point lying on the surface of a geometrical solid, given one projection of this point;

(2) to construct two other projections of a random line contained in the surface of a geometrical solid, given one projection of this line.

8. PROJECTIONS OF A POINT LOCATED ON THE SURFACE OF A GEOMETRICAL SOLID

If one projection of a point lying on the surface of a geometrical solid is given, then another projection of this point can be determined using either of the following two methods. Prior to using them it is necessary to find in the drawing two projections of the surface containing the given point.

The first method of solving this problem is very simple and is employed when the required surface is projected as some line on one of the projection planes. For instance, (a) the horizontal projection of a cylindrical surface with the elements perpendicular to the plane *H* (Fig. 229*a*) is a circle; (b) the horizontal projection of the surface of a right regular hexahedral prism with the faces perpendicular to the plane

H represents six line-segments which are the sides of a hexagon (Fig. 229*b*).

In these cases, given the vertical projection a' of the point A lying on the side surface of the cylinder (Fig. 229*a*) or prism (Fig. 229*b*), the horizontal projection of this point is found in the usual way by vertically projecting the point a' on the horizontal projection of the geometrical solid.

If the point is given on the visible (front) half of the cylinder, then the horizontal projection a of the point A will be found on the lower semi-circle of the horizontal projection of the cylinder's side surface. If the point is given on the rear (invisible) half, the horizontal projection of the point will be found on the upper semi-circle. In this case the letter designating the vertical projection of the point should be enclosed in brackets to indicate that the point is invisible.

The second method is used when both projections of a geometrical surface are plane figures, say, the surfaces of a cone or pyramid.

Fig. 229*c* and *d* illustrates the use of the second method for a right circular cone and a pyramid. These problems can be solved in two ways.

First way. Given the vertical projection a' of a point A lying on the conic surface (Fig. 229*c*). To find the horizontal projection of the point A draw the vertical projection of the element passing through the point a' and the cone's vertex (point s'). Then construct the horizontal projection of this element which will pass through the horizontal projection of the vertex, s, and the end of this element (point b) located on the circle which is the true size of the cone's base.

To complete the construction, project the given point a' on the horizontal projection of the element.

Second way. Same assignment (Fig. 230*a*). The auxiliary line passing through the point A will be a circle parallel to the plane H and situated on the conic surface. The vertical projection of this circle is a horizontal line.

The required horizontal projection of point A will be located on the horizontal projection of the auxiliary circle and is obtained by vertically projecting the point a' on this circle.

The problem of finding the second projection of point A lying on the surface of a pyramid is solved in much the same way, the first method being illustrated in Fig. 229*d*.

The second way of solving the same problem but this time for a tetrahedral pyramid is illustrated in Fig. 230*b*. In this case through the point a' draw an auxiliary horizontal line AB situated on a face. The horizontal projection of this line is parallel to the appropriate edge of the base and will pass through the point B (point b is obtained by direct projecting of point B located on the edge).

The required point a is obtained by project-

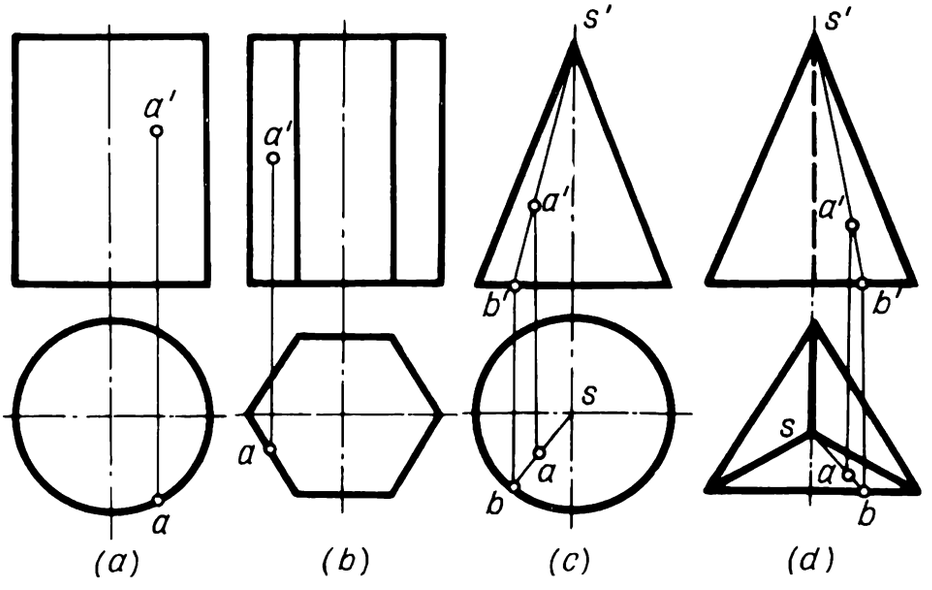


Fig. 229

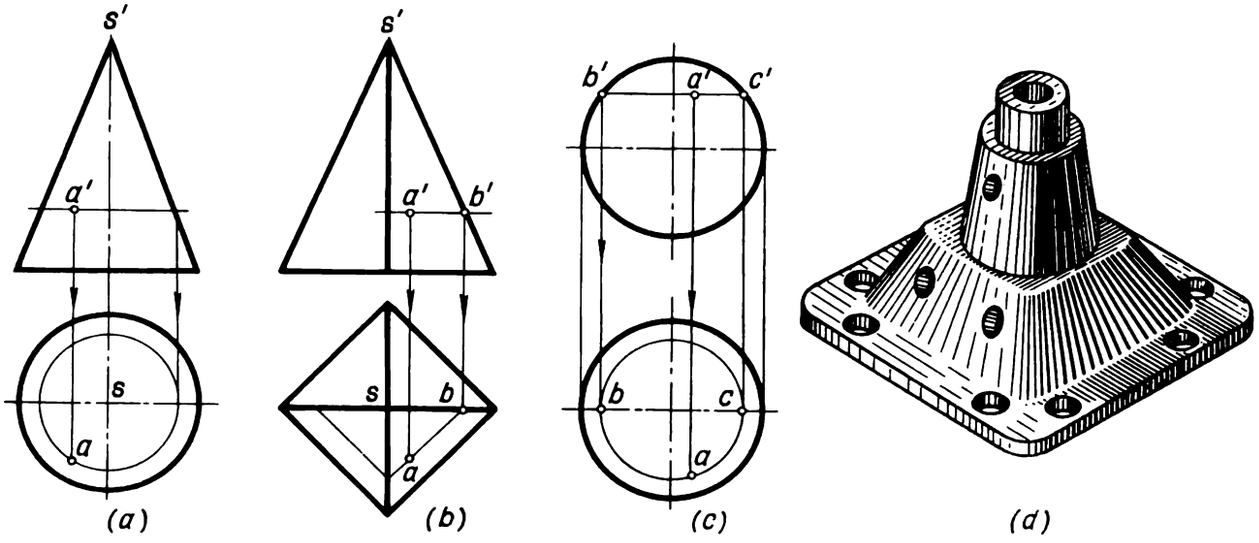


Fig. 230

ing the given projection of the point, a', on the horizontal projection of the auxiliary line.

If a point a' is located on a spherical surface (Fig. 230*c*), then the auxiliary line drawn through the point is a circle contained in a plane parallel to a projection plane (in this case in a plane parallel to the plane H). The required horizontal projection a of the point is found on the horizontal projection of the auxiliary circle which is true size.

The diameter of the auxiliary circle is obtained from the vertical projection on which it is projected as the length $b'c'$.

Fig. 230*d* shows a pictorial representation of a hood lid with several small-diameter holes.

In making a drawing of the lid it is necessary to correctly construct the projections of the hole centres situated on the surface of a pyramid and a cone.

This is done by making use of the above constructions. When the vertical projection of the required points is given, their horizontal projection should be constructed employing the second method illustrated in Fig. 230*a* and *b*.

If point A lies on the surface of a circular ring, use is made of auxiliary circles which pass through the given point A and are situated on the surface of the ring in a plane perpendicular to the ring axis (Fig. 231).

Given the vertical projection a' of the point A on the ring surface, the required second projection (in this case the profile projection) is constructed in the following way. Through a' draw the vertical projection of the auxiliary circle which will be the vertical line-segment $b'c'$. Then construct the profile projection $b''c''$ of this circle which will be its true size and project the point a' on it by drawing a horizontal projecting line.

If the profile projection d'' of a point D located on the surface of this ring is given, the vertical projection of this point is found as follows. Draw the profile projection of the auxiliary circle of radius $o''d''$ through the point d''. Then project the upper (e'') and lower (f'') points of this circle on the vertical projection of the generating circle of radius r to obtain points e' and f'. Join these points by a vertical line which will be

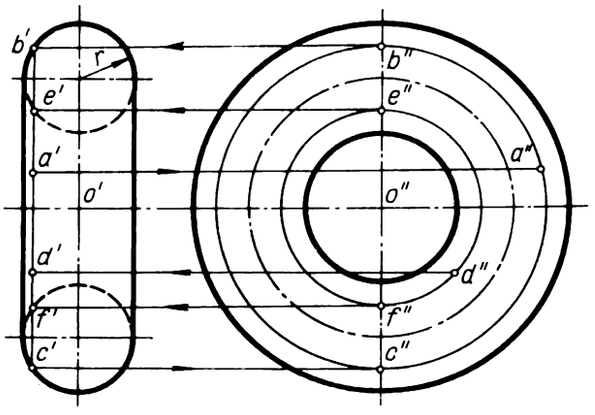


Fig. 231

the required vertical projection of the auxiliary circle (it will be invisible).

The same methods of construction are applicable for points situated on the surface of a torus.

9. PROJECTIONS OF LINES SITUATED ON SURFACES OF GEOMETRICAL SOLIDS

As is known, each line consists of points. That is why all the above methods may be applied in solving the problems considered below.

The problems of constructing two projections of straight lines located on a cylinder (Fig. 232*a*) and a right prism (Fig. 233*a*) are the easiest to solve. It is more difficult to solve such problems with lines lying on the surface of a pyramid (Fig. 234*a*) or a cone (Fig. 235*a*).

Suppose, on the surface of a right circular cylinder (Fig. 232*a*) the vertical projections of two lines are given: $a'b'$, a section of a vertical line (a portion of the generating line) and $c'd'$, a section of an arc situated in a horizontal plane.

All the horizontal projections of the points forming the line AB and the arc CD will be found on the horizontal projection of the cylinder base; moreover, the horizontal projections of all the points of AB will merge into one point ab.

Now the problem is quite simple: having the

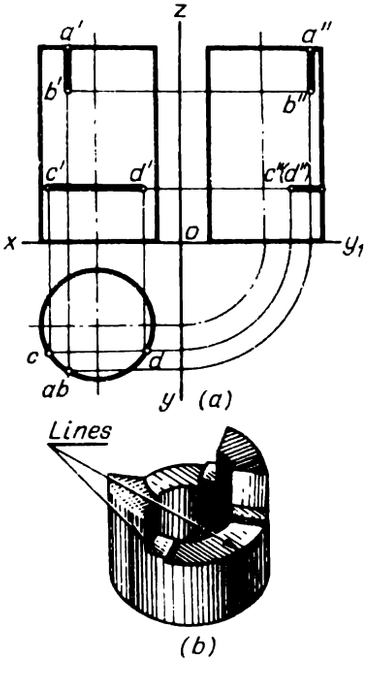


Fig. 232

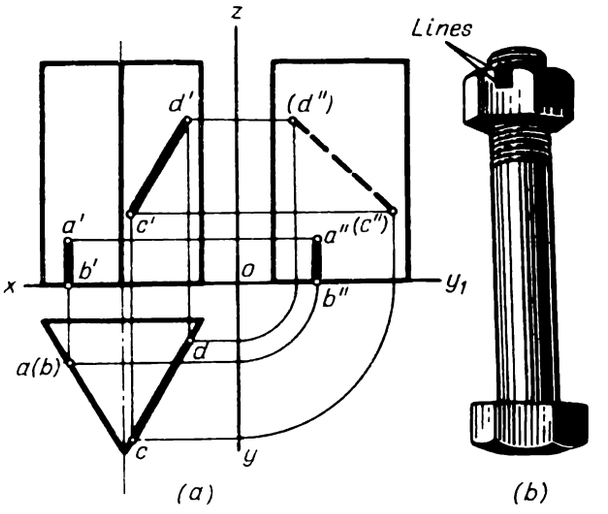


Fig. 233

two projections of the line AB it is not difficult to determine its profile projection ($a''b''$).

The horizontal projection cd of the arc coincides with that of the circle representing the cylinder base. The profile projection of this arc, found according to the general rule of projecting, is a short section $c''(d'')$ of a horizontal line, the portion of this line limited by the point (d'') and the extreme element of the cylinder being invisible (that is why d'' is in brackets).

A practical application of the foregoing method is the drawing of a jaw clutch shown in Fig. 232*b*. Its cylindrical surface contains a number of vertical lines similar to AB and several arcs similar to CD.

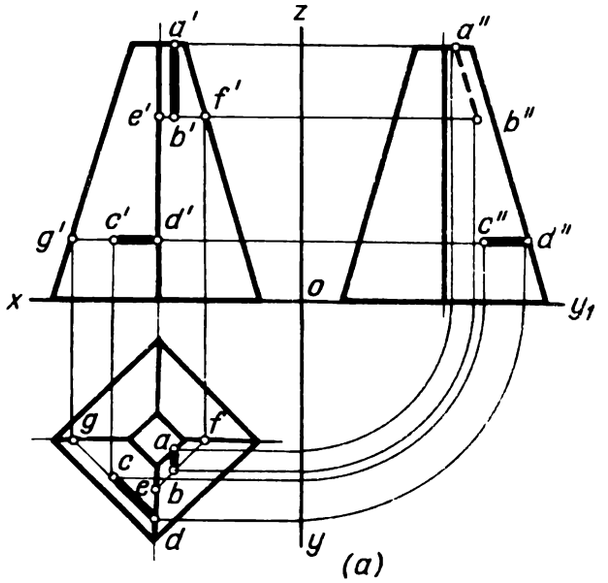
Situated on the side surface of a right trihedral prism (Fig. 233*a*) are two straight lines: a vertical line AB and an inclined line CD with their vertical projections $a'b'$ and $c'd'$ given.

First find the horizontal projections of these lines which are situated on the triangle representing the horizontal projection of the prism surface. Then determine the profile projections a'', b'', c'', and d''.

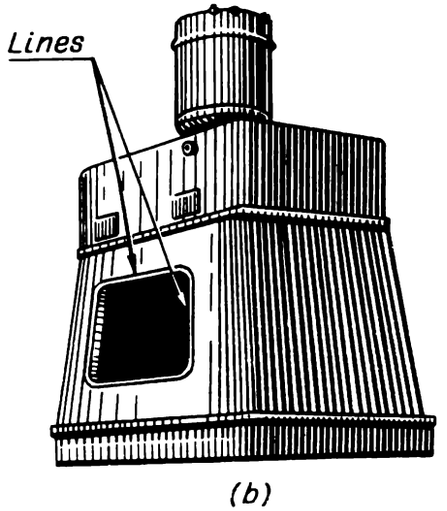
If the prism is considered to be opaque, then the profile projection of CD is invisible; that is why it is drawn in a dashed line and the letters c'' and d'' are enclosed in brackets.

Fig. 233*b* illustrates a bolt and a nut. The nut, having the shape of a hexahedral prism, is provided with slots whose edges are straight lines situated on the surface of a right prism. Some of these lines are vertical like AB in Fig. 233*a*, and some are horizontal.

A more complicated example is illustrated in Fig. 234*a*. Given are the vertical projections $a'b'$ and $c'd'$ of line-segments located on two faces of the pyramid. The horizontal projection of AB is constructed from two points. Point a is determined by projecting the point a' directly on the horizontal projection of the upper (smaller) base of the pyramid. Point b is found with the aid of an auxiliary horizontal line $e'f'$ drawn through the point b' parallel to the bases. First construct the horizontal projection of the auxiliary line from two points E and F which are the points of intersection of this line with two adjacent edges. Then project point b' on the line ef.



(a)



(b)

Fig. 234

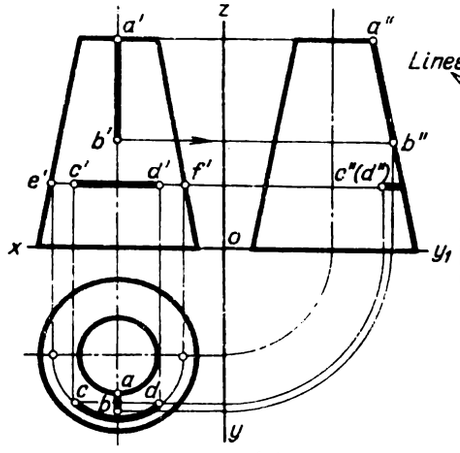
The horizontal projection of CD is determined in the same way. This time the construction is simplified, since CD is a horizontal line. There is no need to draw an auxiliary horizontal line for determining the point C. It is sufficient to extend CD until it intersects with the pyramid edge at point G.

The profile projections of AB and CD are constructed using the general method of determining the third projection of a point with its two projections given. The points a'', b'', c'', d'' thus found are then joined in pairs.

A practical application of such constructions is illustrated in Fig. 234*b*. The mid-portion of the casing of a multiple drilling machine is a tetrahedral truncated pyramid with an opening cut along two vertical and two horizontal lines. The projections of horizontal lines are constructed in a manner similar to that adopted for CD, and those of vertical lines, like AB (Fig. 234*a*).

A conic surface may contain the following lines which are frequently found in machine parts, tools, etc.:

(1) *A straight line*, which is the generatrix of a conic surface. A section AB of such a generating line (element) is given in Fig. 235*a* presenting the drawing of a right circular cone. It is easy to construct the projections of AB, since it lies on an extreme element which is parallel to the profile plane of projection. First find the profile projection $a''b''$ by drawing, through the points a' and b', horizontal projecting lines to intersect the mentioned extreme element at points a'' and b''. Then determine the horizontal



(a)

(b)

Fig. 235

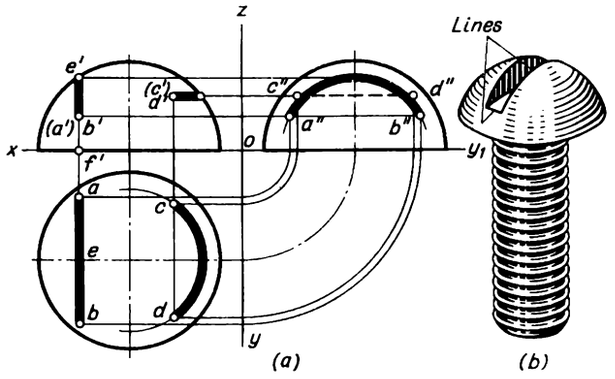


Fig. 236

projection *ab* by means of direct projecting following the above recommendations.

(2) A *circle*, which is contained in a plane perpendicular to the axis of a right circular cone. Given the vertical projection *c'd'* of an arc of such a circle, it is very simple to find its horizontal projection. To this end, from the common centre of the circles representing the bases of the cone on the plane *H* and with a radius equal to half the length *e'f'* describe the required arc (the given section *c'd'* is extended on both sides to intersect the extreme elements at points *e'* and *f'*).

The downward projecting lines drawn through the points *c'* and *d'* limit the length of the horizontal projection of the arc *cd*.

The profile projection *c''*(*d''*) of this arc is determined by following the usual procedure. The profile projection *d''* is given in brackets as *D* is closer to the plane *W* than *C*.

(3) *Non-circular curves: ellipse, hyperbola, parabola.* The projections of these conic sections are more difficult to construct. Given one projection of such a curve, the other two are constructed from many points taken on the line using any of the methods illustrated in Figs. 229*c* and 230*a*.

Fig. 235*b* gives a picture of a taper socket for drills. To make a drawing of this tool it is necessary to accomplish the above constructions when representing the transverse grooves and longitudinal slot.

(4) *Lines on a spherical surface* are always circular arcs. Projections of these arcs differ depending on the position of the plane containing the arc in respect to the projection planes. Circles are projected true size on the projection plane parallel to which they are situated. The other two projections will be straight lines.

If arcs are contained in planes which are not parallel to the planes of projection, then their projections will be portions of ellipses. Given any one projection of such an arc, the other two projections are determined by making the construction illustrated in Fig. 230*c*. In this case we have to take a sufficient number of points on the given projection of the arc.

Given in the drawing of a hemisphere (Fig. 236*a*) are the vertical projections, *a'b'* and *c'd'*, of two arcs. The arc *AB* is located in a profile plane, i.e., in a plane perpendicular to the planes *H* and *V* and parallel to the plane *W*. Hence, the vertical and horizontal projections of this arc are line-segments. The length of the horizontal projection, *ab*, of the arc is determined after constructing the profile projection, *a''b''*,

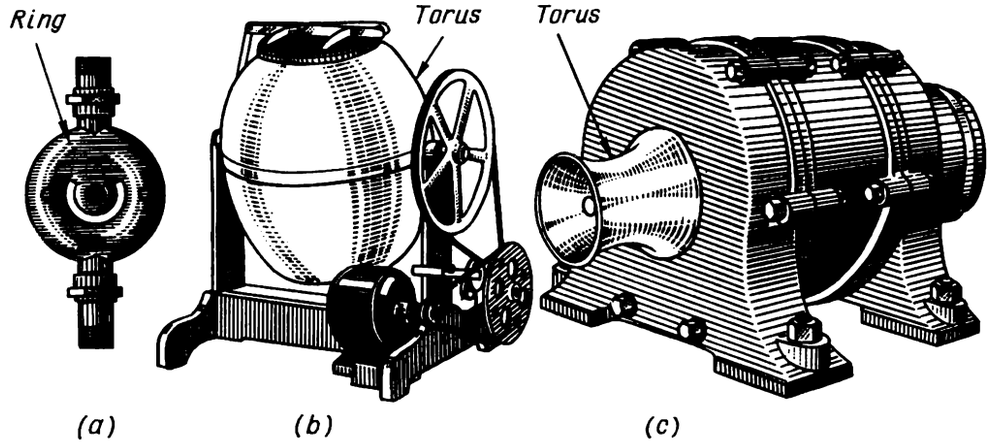


Fig. 237

of the arc, the radius of this arc being equal to the length *e'f''*. The horizontal projection is found according to the general rule of projecting points.

The horizontal projection of the second arc is constructed in the reverse sequence: first find the horizontal projection *cd*, and then the profile projection, *c''d''*.

Fig. 236*b* presents an example of four arcs forming a slot in a spherical screw head. The two longer arcs are situated in a vertical, and two shorter in a horizontal plane.

The projections of the two longer arcs are constructed similarly to those of the arc *AB* shown in Fig. 236*a*, and the projections of the shorter arcs are constructed as those of the arc *CD*.

Shown in Fig. 237*a* is an ejector designed for pumping out hot water and used in industrial installations. Its casing has a *ring-like surface.*

Tore surfaces are widely used in designing machine elements, instruments, machine tools, and apparatus.

The mixer casing and the drum shown in Fig. 237*b* and *c*, respectively, incorporate toruses.

On learning the methods of finding the projection of points and lines lying on various geometrical solids, we can construct openings of any shape cut in these solids.

Fig. 238*a* presents a two-view drawing of a right circular cylinder with a slot bounded by two vertical and two horizontal planes. As is seen from the drawing, the cut has the shape of the capital letter *T* turned upside-down.

The third (profile) projection of this cylinder can be constructed as in Fig. 232*a*.

The projections of the cylinder elements, along which the cut is made by vertical planes, are

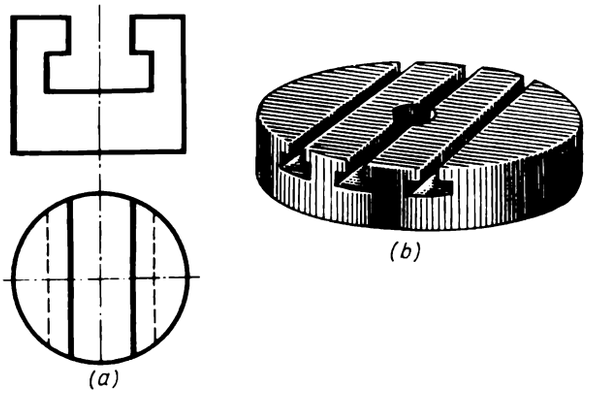


Fig. 238

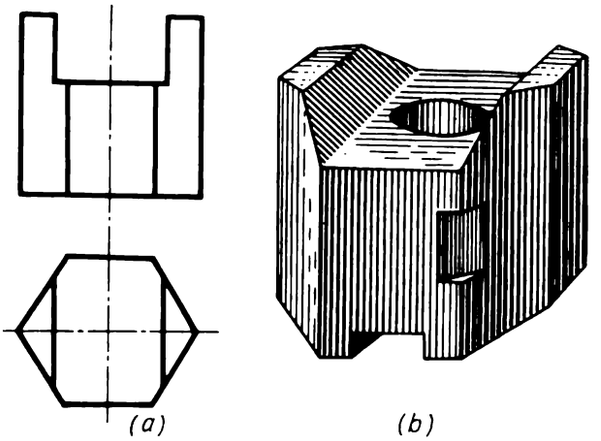


Fig. 239

found in the same way as those of the element *AB* in Fig. 232*a*.

The profile projections of the arcs cut by the horizontal planes are determined in the same manner as the profile projection *c''d''* of the arc *CD*.

Illustrated in Fig. 238*b* is the face plate of a vertical turret lathe which is a short cylinder of a considerable diameter provided with slots for the fastening bolts.

Fig. 239*a* gives two projections of a right hexahedral prism with a slot at the top. To obtain the third projection of the prism do as indicated in Fig. 233*a*.

The projections of the slot edges located on the side surface of a right prism are found as illustrated in Fig. 233*a* for constructing the projections of *AB* and *CD*.

The ram of a pneumatic hammer pictured in Fig. 239*b* is an octahedral prism having a rectangular slot at the bottom and a trapezoidal one at the top. In making the drawing of this part use the construction presented in Fig. 233*a*. In this case the construction of the projections of the edges of the slots will also be similar to that of the projections of the lines *AB* and *CD* in Fig. 233*a*.

Two projections of a truncated cone having a trapezoidal or a rectangular slot (Fig. 240*a* and *c*) can be constructed using the methods illustrated in Figs. 230*a* and 235*a*. The vertical cutting planes, which are parallel to the axis of the cone, will cut its surface along lines whose profile projection is a hyperbola. The latter has to be constructed from many points which are found by the construction method shown in Fig. 230*a*.

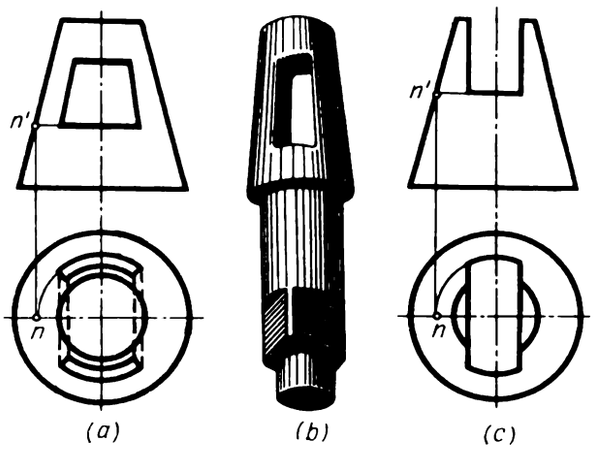


Fig. 240

Mark a series of points on the vertical projection of the slot edge, and first determine their horizontal projections and then the profile ones.

The horizontal cutting planes will cut the cone along arcs of circles whose projections are found by a method similar to that employed for determining the projections of the line *CD* in Fig. 235*a*.

The principal working element of the cock plug presented in Fig. 240*b* is a cone with a quadrangular through hole, whose two projections are constructed as in Figs. 235*a* and 240*a* and *c*.

The through trapezoidal and rectangular holes in the tetrahedral truncated pyramids of Fig. 241*a* and *b*, respectively, are easy to construct by following the instructions for constructing the straight lines *AB* and *CD* lying on a pyramid (see Fig. 234*a*), the only difference being that the line representing the edge cut by horizontal planes must be extended to meet any edge of the pyramid. Next the points of intersection *M* and *N* lying on the edge are projected on its horizontal projection. Then draw the horizontal projection of the extended line of the cut and project on it the ends of the line.

The stand shown in Fig. 241*d* is bounded by the surface of a truncated tetrahedral pyramid and has a through opening of trapezoidal shape which can be constructed on a drawing using the methods shown in Figs. 234*a* and 241*a*.

A more complicated slot at the bottom of the trihedral truncated pyramid in Fig. 241*c* is constructed with the aid of auxiliary lines similar to the line *EF* in Fig. 234*a* or by extending the vertical projection of the line of cut to intersect the edge at point *n'*.

The slots in the hemisphere shown in Fig. 242*a* can be constructed by the method considered in Fig. 236*a*. Here the projections of the arcs, along which the horizontal planes cut the hemisphere, are constructed as the arc *CD* in Fig. 236*a*.

The body of the testing instrument pictured in Fig. 242*b* represents a hemisphere with a side recess formed by a horizontal and a vertical plane. The two projections of the arcs are similar to those shown in Fig. 236*a*.

From constructing geometrical solids with openings we can pass over to determining the third projection of a model bounded by geometrical surfaces with its two projections given.

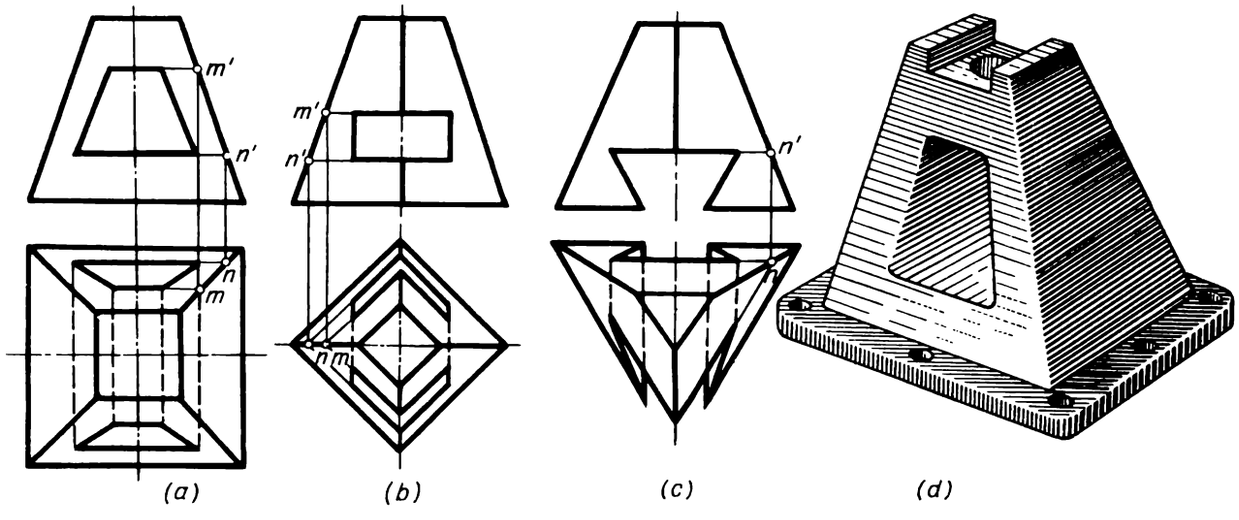


Fig. 241

To successfully solve such problems, which are the basic exercises in making and reading engineering drawings, it is necessary to master the methods of constructing the third projection (with the two projections given) of the following geometrical elements:

(1) point;

(2) straight line in different positions with respect to the projection planes;

(3) plane curve specified by several points;

(4) plane figure: triangle, rectangle, trapezium, quadrangle, and circle in various positions in respect to the planes of projection;

(5) simple geometrical solids: right prism, pyramid, right circular cylinder, cone, sphere, ring, and torus.

Prior to solving such problems, read the two-view drawing of the given model so as to visualize the geometrical shapes of the model.

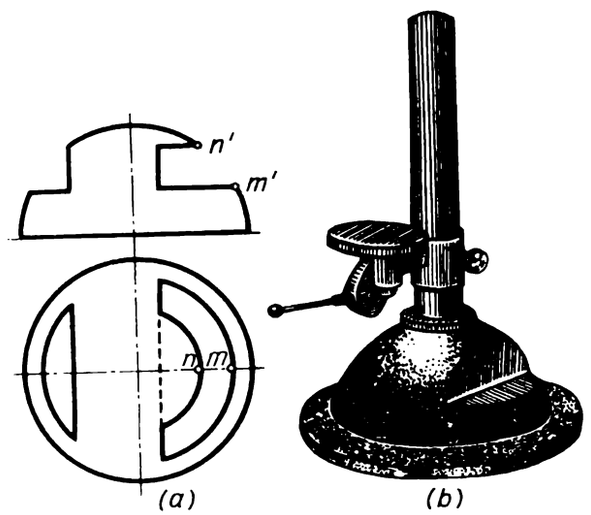


Fig. 242

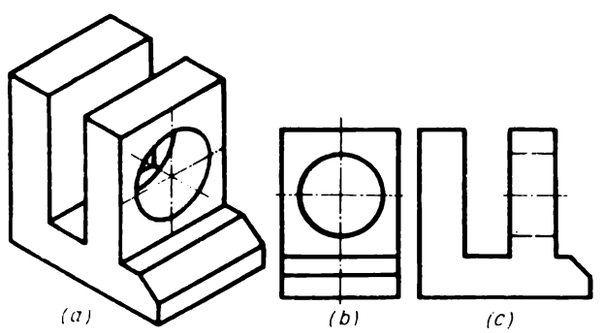


Fig. 243

In reading the drawing the use of both given projections is mandatory, since one projection is insufficient for this purpose. Thus, it is impossible to conceive a clear idea as to the shape of the model shown in Fig. 243*a* judging only by one projection, say, the vertical one presented in Fig. 243*b*, since a variety of figures can be imagined, whose profile projections are given in Fig. 244.

If, in reading the drawing, consideration is given to both projections (Fig. 243*b* and *c*), then only one shape (shown in Fig. 243*a*) can be singled out in our imagination.

The solution of this problem is checked by constructing the third projection of the model as in Fig. 245.

When reading a two-view drawing of a model the latter should be dismembered mentally into

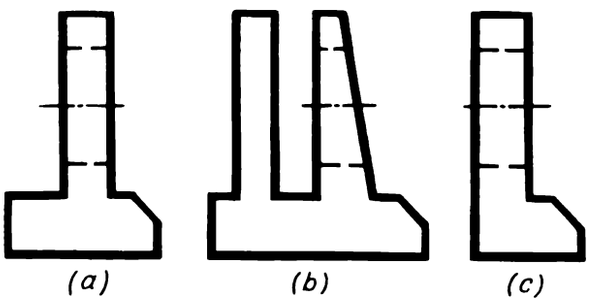


Fig 244

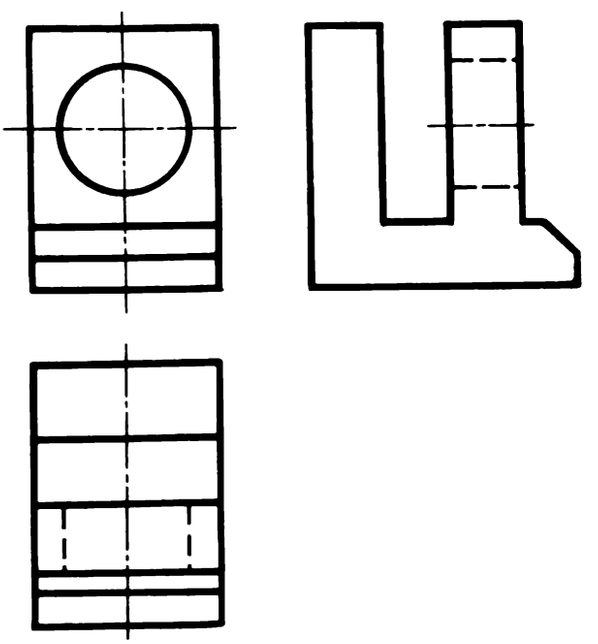


Fig. 245

elementary geometrical solids whose profile projection should be pictured. After this preparatory stage we can proceed with the third projection of the model by gradually making all the necessary constructions in the order of increasing complexity.

Questions

1. What is the sequence in constructing the projections of a right circular cylinder whose base is situated on the vertical plane of projection? Same for a right hexahedral pyramid.
2. What are the construction methods for determining the missing projections of points lying on the surface of a cone, sphere, and a torus?
3. How to find the missing projections of lines located on the surface of a prism, a pyramid, and a cylinder?
4. What principle underlies the construction of geometrical solids cut by planes parallel to the projection planes?
5. What should special attention be given to when reading the drawing of a model?
6. What is the sequence in constructing the third projection of an object with two projections given?

Exercise 48

Construct the third projection of the geometrical solids shown in Fig. 246*a* through *d*, and also the missing projections of the points *A* and *B* and the line *CD* located on their surfaces.

Construct the vertical and profile projections of a group of the same geometrical solids with their horizontal projections given (Fig. 246*e*).

Exercise 49

Draw the necessary number of projections for each model pictured in Fig. 247.

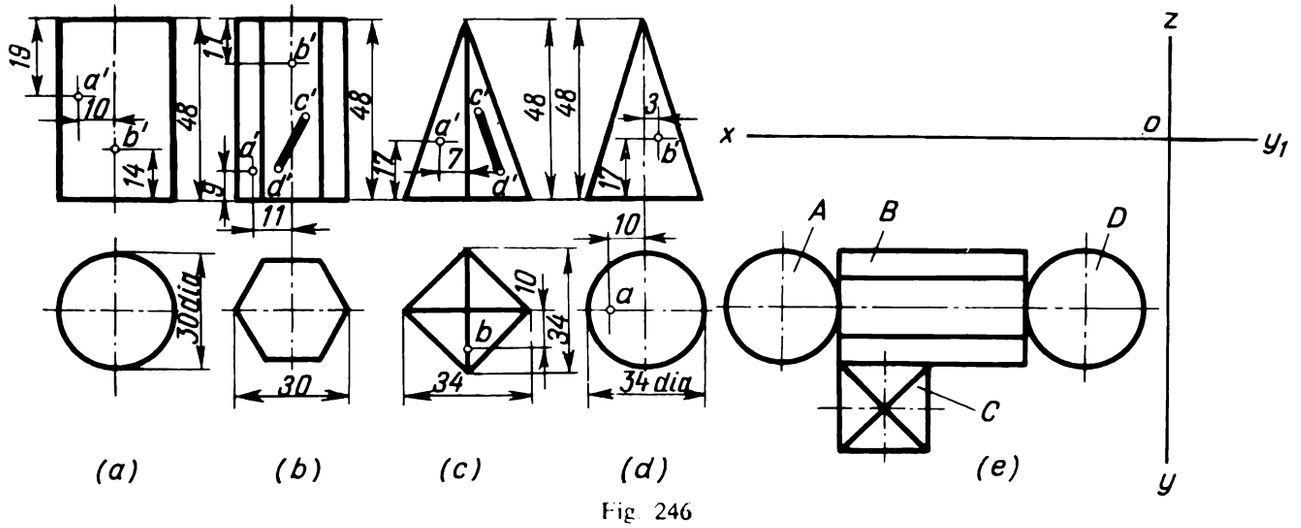


Fig. 246

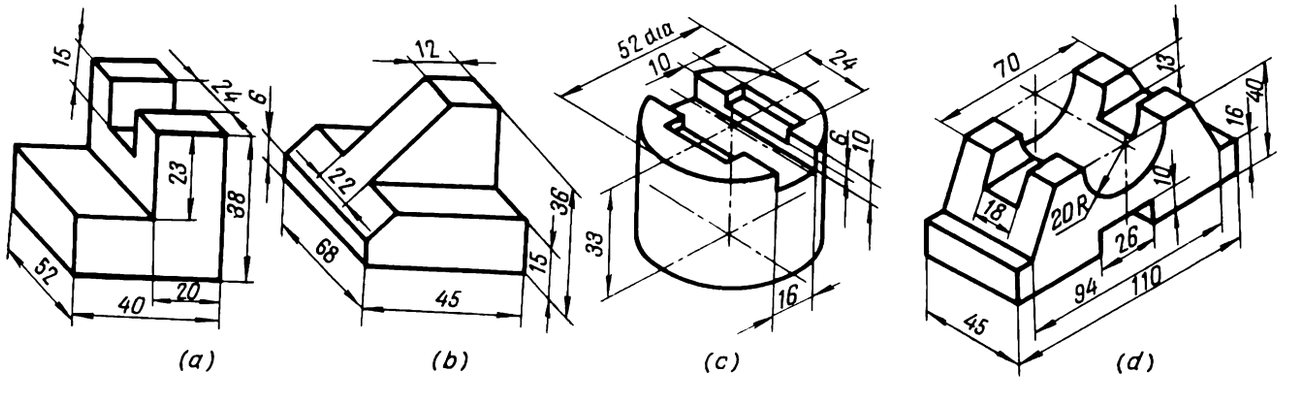


Fig. 247

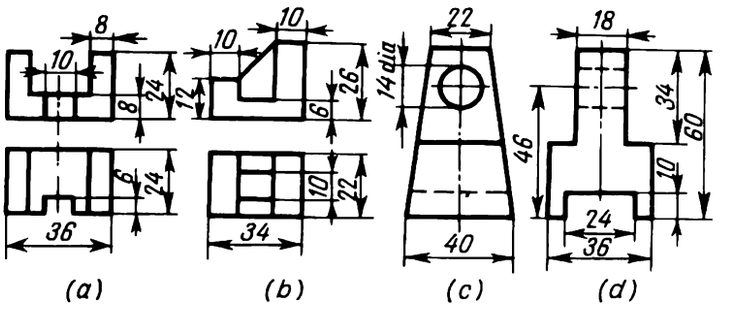


Fig. 248

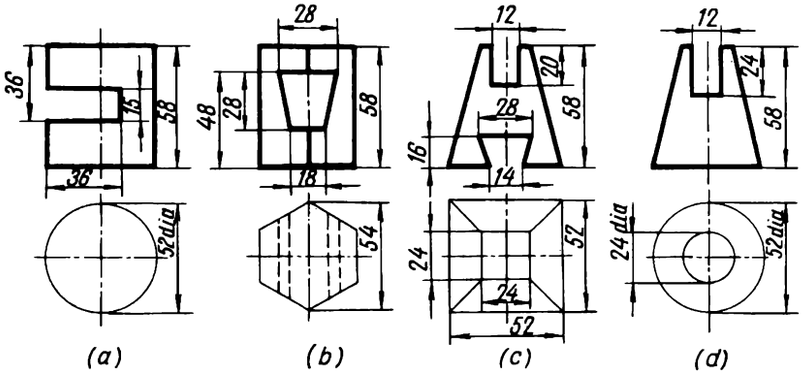


Fig. 249

Exercise 50

Construct the third projections of the models presented in Fig. 248.

Exercise 51

Draw full-size vertical projections of the models shown in Fig. 249. Construct the horizontal and profile projections.

CHAPTER 9

CUTTING GEOMETRICAL SOLIDS WITH PLANES. DEVELOPED SURFACES OF GEOMETRICAL SOLIDS

1. GENERAL CONCEPTS

If a machine part or an element thereof is cut by a plane, then a plane figure is obtained on the cutting plane. This figure is called a section. Construction of projections of such sections is often necessary in making drawings of various machine parts. In addition, developed surfaces of machine parts cut by a plane have to be constructed to enable sheet material to be cut out for parts of various ducts, ventilating devices, machine casings, machine-tool guards, etc. (see Fig. 250).

To master the fundamentals of projection drawing it is highly important to exercise in constructing orthographic and axonometric projections of truncated solids, and also in constructing various sections and developed surfaces of these solids in true size. In doing so, the construction methods and rules considered in the previous chapters are utilized.

Illustrated in Fig. 251 is a cube placed on the horizontal plane of projection and cut by three different planes.

In the first case (Fig. 251*a*) the cube is cut by a vertical projecting plane *P* and the section has

a rectangular shape. For the sake of pictorialness the section produced by the cutting plane may be cross-hatched.

When constructing two projections of this section (Fig. 251*b*), it should be borne in mind that the vertical projection of the section coincides with the vertical trace of the cutting plane P_V.

The horizontal projection of the section is bounded on its right by a straight line, along which the cutting plane *P* intersects the upper base of the cube.

In the second case (Fig. 251*c*) the cube is cut by a horizontal projecting plane *P*. The section is also a rectangle, but this time of a different size and position.

The projections of this section are constructed in Fig. 251*d*: the horizontal projection coincides with the horizontal trace P_H of the cutting plane, the vertical projection presenting a rectangle whose one side is the line along which the cutting plane *P* intersects the front face of the cube.

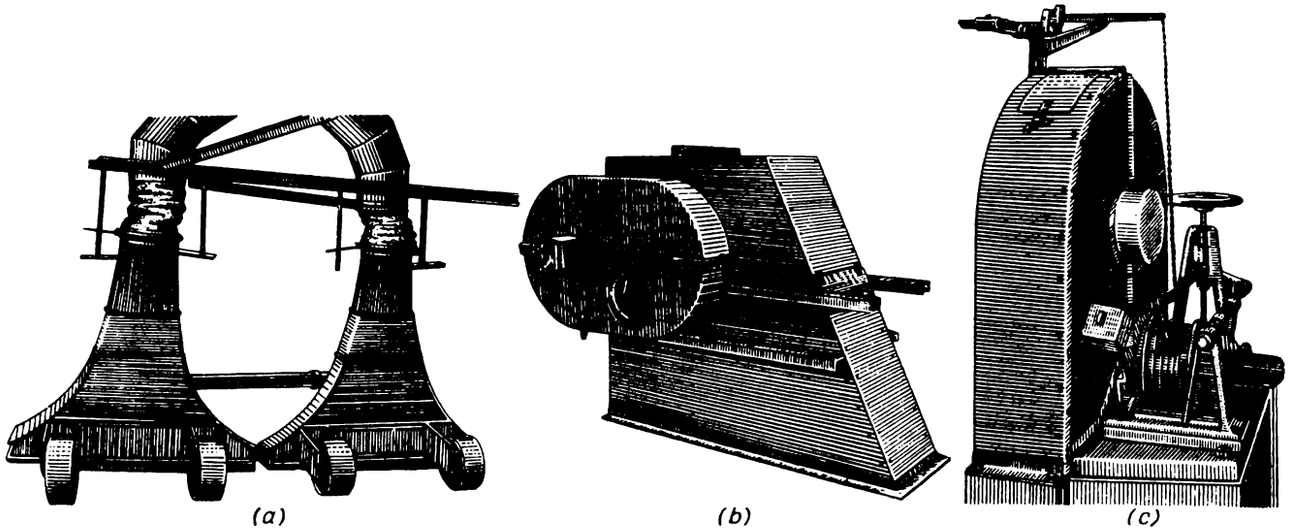
In the third case (Fig. 251*e*) the cube is cut by an oblique plane, and the section is a triangle.

The projections of such a figure (Fig. 251*f*) are constructed from its vertices which are found with the aid of auxiliary lines drawn in the cutting plane and passing through the required points. For instance, the projections of the point *A*, one of the triangle's vertices, lying on the front left-hand edge of the cube are found in the following way. Since the horizontal projection of this edge is a point, the horizontal projection *a* of the vertex *A* will coincide with this point. In the plane *P* draw a horizontal line through the point *A*. The horizontal projection of the horizontal line must pass through the point *a* and be parallel to the horizontal trace P_H of the cutting plane.

The vertical projection of the vertex, *a'*, is found by projecting the point *a* on the vertical projection of the horizontal line (it will be parallel to the axis *ox*).

The projections of the vertex *B* are determined as follows.

The point *B* belongs both to the upper *(I)* and the front *(II)* faces of the cube (Fig. 251*e*). Hence, its projections on the orthographic drawing (Fig. 251*f*) will be found on the corresponding projections of these faces. Face *I* is projected onto the plane *V* as a straight line. It is quite obvious that the vertical projection *b'* will lie on this line. Draw a horizontal line through the above mentioned line and determine the horizontal projection *b* by finding the horizontal projection of the horizontal line. It will be the point of intersection of this projection and the horizontal projection of face *II* on the plane *H*. The vertical projection *b'* is determined by projecting the point *b* on the vertical projection of the horizontal line. The projections of section figures are cross-hatched with thin parallel lines slanted at an angle of 45°.



(a) *(b)* *(c)*

Fig. 250

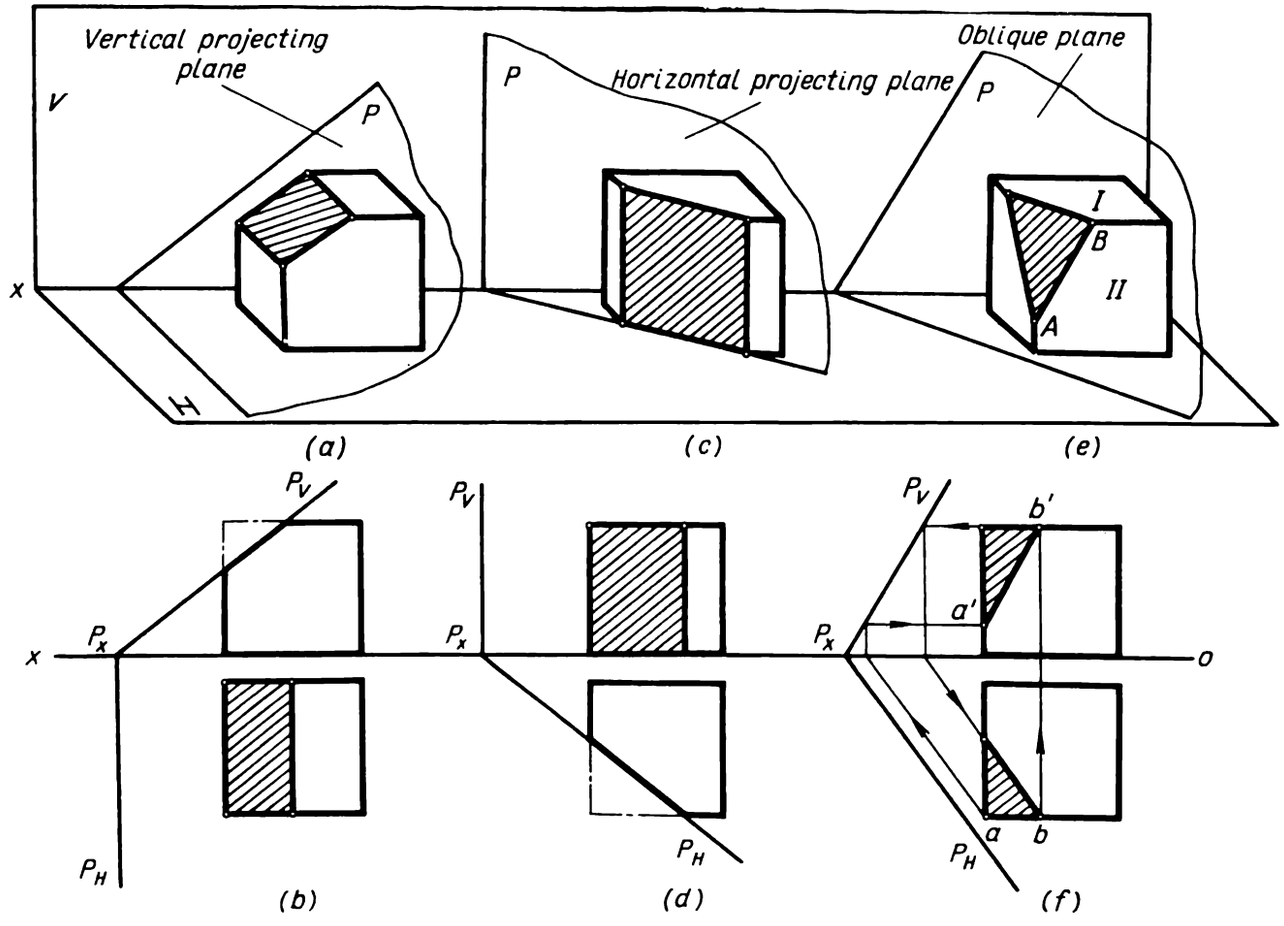


Fig. 251

2. INTERSECTION OF A PLANE AND A PRISM. DETERMINING THE TRUE SIZE OF THE SECTION AND CONSTRUCTING A DEVELOPED SURFACE OF A PRISM

Consider a right pentahedral prism cut by a vertical projecting plane P (Fig. 252*a*); given are three projections of the prism.

The *projections of the section* are constructed using the following method.

Find the projections of the points of intersection of the plane P and the edges of the prism, and join them with straight lines. The vertical projections of the intersection points will lie on the vertical trace P_V of the plane P, as these points belong both to the plane P and to the vertical projections of the prism edges, i.e., they lie at the points of intersection of the vertical projections of the edges and this trace: 1′, 2′, 3′, 4′, and 5′. The horizontal projections of the intersection points (*1* through *5*) will coincide with the horizontal projections of the edges. Having two projections of the points, find their profile projections *1″* through *5″* by making use of the general method of projecting. Join the points *1″* through *5″* thus obtained by straight lines to construct the profile projection of the section.

The true size of the section can be determined using any one of the three *methods of transforming projections* considered in Part Three, Chapter 5. In the given example (Fig. 252*a*) this is achieved by replacing planes of projection. The horizontal plane of projection is replaced with a new one, the new axis of projection o_1x_1 being assumed to coincide with the vertical trace of the plane P. To find the new horizontal projection of any point of the section (say, point *1*) do the following. Erect a perpendicular to the

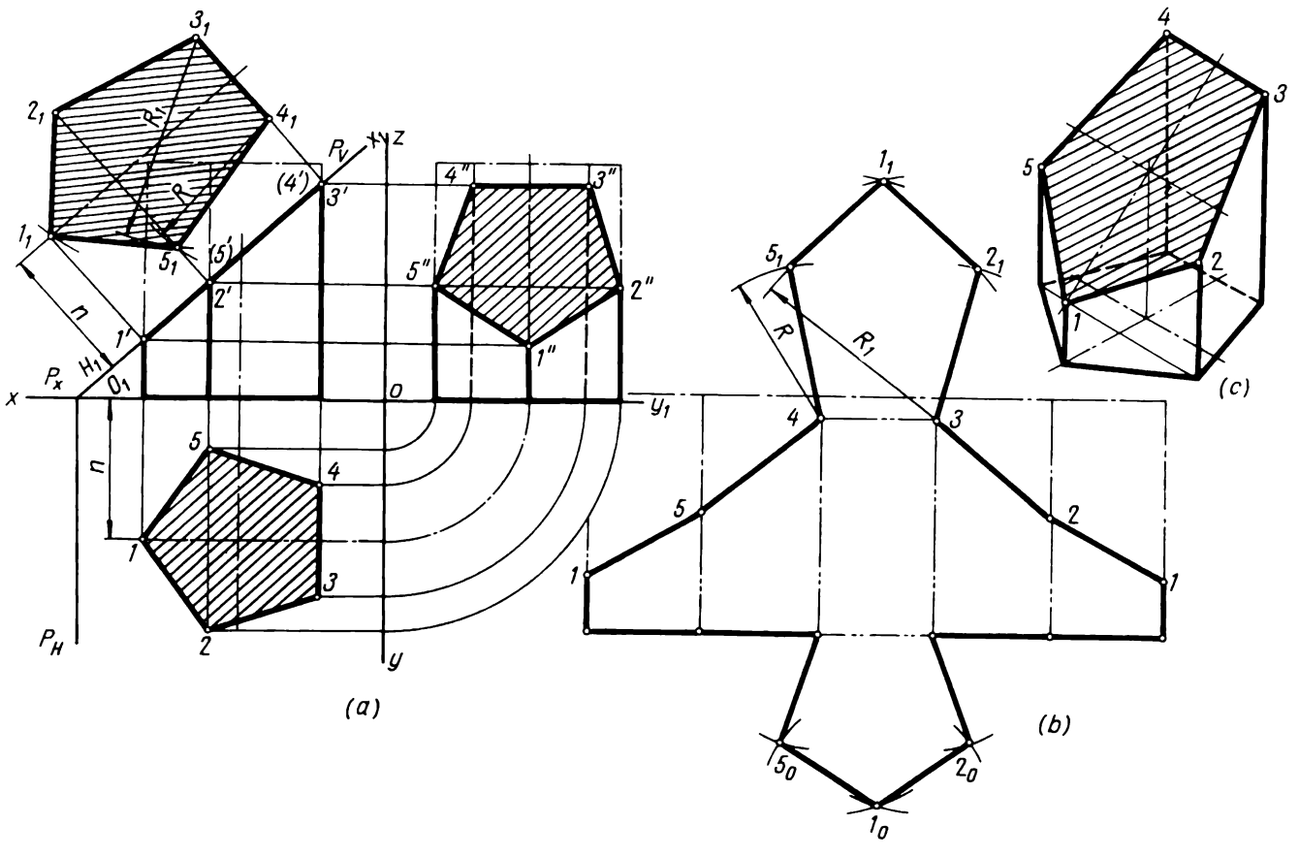


Fig. 252

new axis o_1x_1 at point *1′* and lay off on it the distance between the former axis *ox* and the former horizontal projection of point *1*, i.e., the length *n*. The new horizontal projections of points *2*, *3*, *4*, and *5* are constructed in the same way. Join the new horizontal projections of the five points with straight lines to obtain the true size of the section.

To make a model of a geometrical solid one must have an appropriate pattern or development of its surfaces. The complete surface of a geometrical solid laid out in a plane is called the development of the solid. The surface of some solids, for example, that of a sphere, cannot be developed in one plane. Such surfaces are called non-developable.

The developed surface of a prism complete with a base and a section is constructed in the following way. First draw a horizontal line (Fig. 252*b*) and lay off on it lengths equal to the corresponding sides of the base: *1-2*, *2-3*, *3-4*, *4-5*, and *5-1*.

The true lengths of the sides are transferred from the horizontal projection of the base. Then lay off the true lengths of the corresponding edges of the prism transferring them from the vertical or profile projections of the prism. The five plane figures thus obtained correspond to the side faces of the prism. Attaching the two pentagons (lower base and section) to the developed side surface in the way indicated in the accompanying drawing we obtain the development of the entire surface of the given prism. The pentagons may be constructed using the method of triangulation or that of coordinates, known from geometrical drawing. In constructing vertex *5* in Fig. 252*a* and *b* the method of triangulation was used.

In developments the folding lines, i.e., edges, are drawn in a light chain with two dots.

It is good practice to exercise in constructing truncated solids in axonometric projection (see, for example, the truncated prism in Fig. 252*c*). The sequence of constructing an isometric pro-

jection of the prism is the following: first construct its base in isometry; then draw vertical lines and lay off on them the true lengths of the corresponding edges. Join points *1* through *5*, thus obtained, with straight lines to complete the section of the prism.

A practical example from engineering where the development of a truncated prism is involved is given in Fig. 253. The upper (wide) portion of the loading funnel of a conveyor represents the base of a truncated tetrahedral prism.

Consider an example in which a right trihedral prism is cut by an oblique plane (see Fig. 254).

Since the prism is located on the plane H, the horizontal projection of the section coincides with the horizontal projection of the base. The vertical projection of the section is constructed from three points *(A, B, C)* on the three edges of the prism. To find, for example, the vertical projection of the point A, draw an auxiliary line through it, a horizontal line lying in the plane P. The horizontal projection of this horizontal line is drawn parallel to the horizontal trace P_H of the plane P. With the aid of the vertical projection v' of the vertical trace of this horizontal line find the vertical projection of the horizontal line (which is parallel to the axis ox) and project on it the point a. The vertical projections of the three points thus obtained are then connected with straight lines.

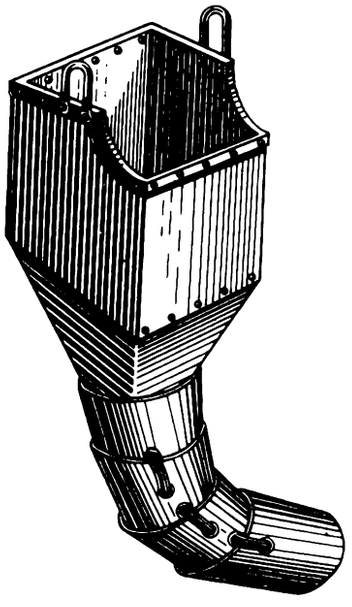


Fig. 253

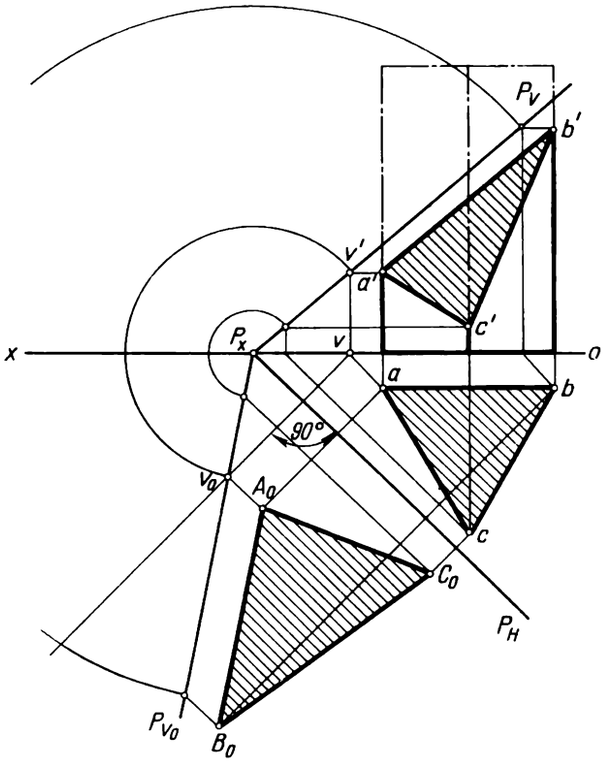


Fig. 254

The true size of the section is found using the coincidence method. First the vertical trace of the plane, P_V, is brought into coincidence with the horizontal plane of projection. It is done in the following way: drop a perpendicular from point v onto the trace P_H. From P_x as a centre and with a radius equal to $P_x v'$ describe an arc to intersect the extension of the perpendicular at point v_0. Join the points P_x and v_0 with a straight line and extend it to obtain the required trace P_{V_0}.

Then apply the coincidence method to three horizontal lines passing through the points A, B, and C of the section and find the new positions of these points, A_0, B_0, and C_0.

Consider the horizontal line passing through the point A. Through the point a draw a straight line parallel to the trace P_H, find the new position v_0 of the vertical trace of the horizontal line and through it draw a new horizontal line which will be parallel to P_H. Then the new projection of the point A will be found at the point A_0 of intersection of the perpendicular dropped from the horizontal projection a to the new projection of the horizontal line and the latter.

3. INTERSECTION OF A PLANE AND CYLINDER. DEVELOPMENT OF A CYLINDER

Cylinders are commonly encountered in design. Three projections of a right circular cylinder cut by a plane are constructed in much the same way as those of the above prism, since the right circular cylinder may be treated as a right prism with an infinite number of edges, elements of the cylinder.

Constructed in Fig. 255*a* are three projections of a right circular cylinder lying on the plane *H*. As is obvious from the drawing, the cylinder axis is parallel to the axis *ox*. The cylinder is cut by a vertical projecting plane *P*.

The plane *P* cuts both the side surface of the cylinder and its left-hand base. We know that a cutting plane making an angle with the axis of a cylinder produces an elliptical section. Hence, in this case, the section will be a portion of an ellipse.

In specific cases, when the cutting plane *P* is parallel to the axis of the cylinder, it cuts a rectangle from the latter. If the plane *P* is perpendicular to the axis, then the section will be a circle of diameter *d*.

The vertical projection of the section coincides with the vertical trace P_V of the plane *P;* the profile projection of the section coincides with that of the base of the cylinder, while the horizontal projection of the section will be a portion

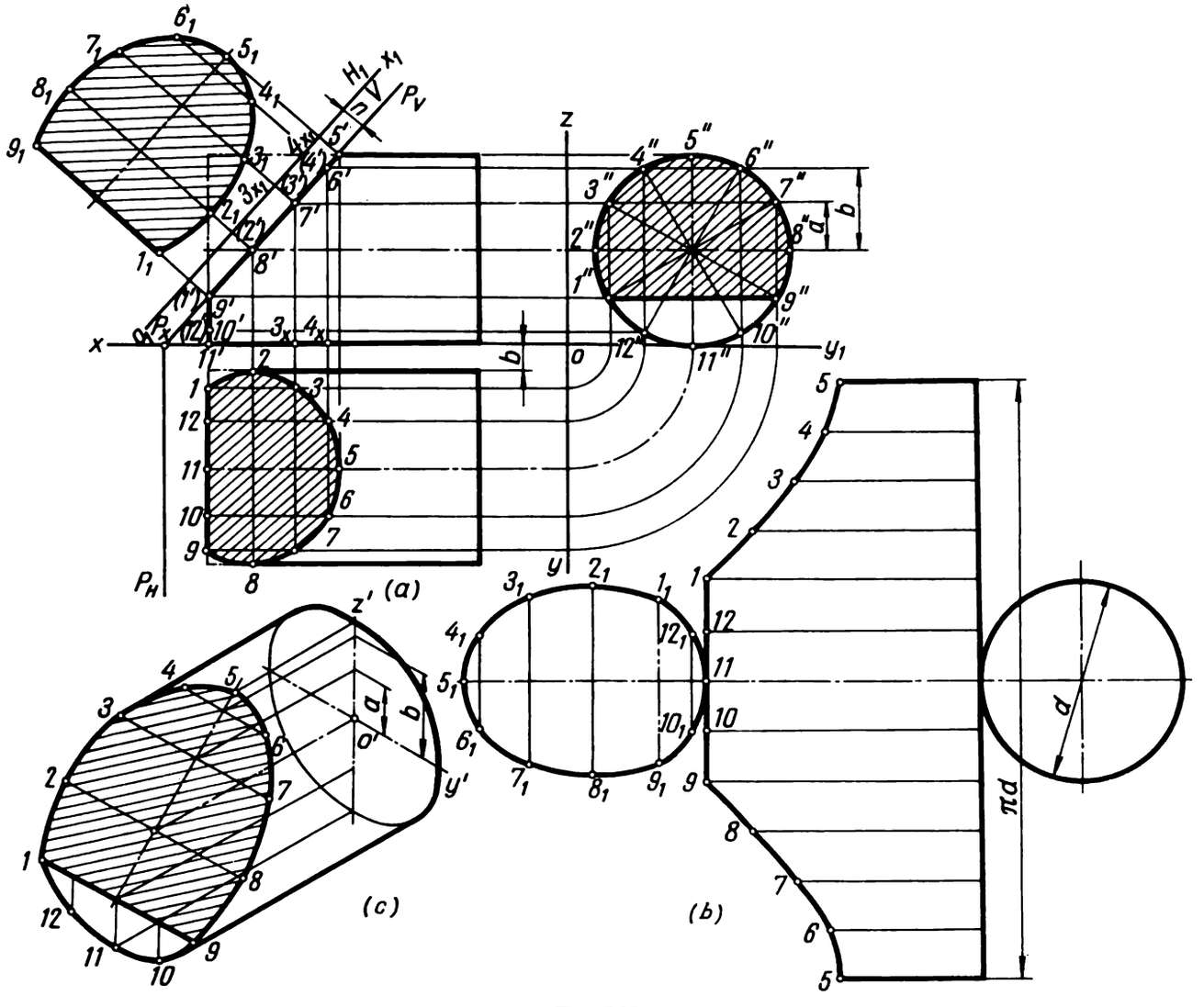


Fig. 255

of an ellipse. Any curve can be constructed point by point. For instance, to construct the horizontal projection of a point belonging to the section (say, point 6), take the vertical projection of this point (6′ on the trace P_V) and transfer it to the profile projection of the cylinder to obtain point 6″. Now, with the two projections known (6′ and 6″), find the third, horizontal, projection (6) of the chosen point making use of the general method of construction. Use a French curve to draw a smooth line through the horizontal projections of the points thus obtained.

In constructing the true size of the section (Fig. 255*a*) the method of replacing projection planes is used. Here the horizontal plane of projection is replaced with a new one and the new axis of projection o_1x_1 is drawn parallel to the trace P_V at an arbitrary distance n, the length $3\text{-}3_x$ being equal to $3_1\text{-}3_{x1}$, and $4\text{-}4_x$ to $4_1\text{-}4_{x1}$.

The developed surface of the truncated cylinder complete with the base and the section is constructed in Fig. 255*b*.

For the sake of convenience the base circle is divided into twelve equal parts and the cylinder is considered a dodecahedral prism. The length of the base circumference, equal to πd, is laid off on a vertical line and divided into twelve equal parts. Draw horizontal lines through the points of division and mark off on them the true lengths of the corresponding elements transferred from the vertical or horizontal projection of the cylinder. The points *1* through *5* and *5* through *9* thus obtained are joined in a smooth line with the aid of a French curve. The section (part of an ellipse) with the remaining portion of the left-hand base (part of a circle) and the right-hand base (circle) are then attached to obtain the complete development.

The construction of the elliptical section in true size can be simplified if on the vertical projection of the cylinder the extreme lower element is extended to the left so that the plane *P* completely cuts its side surface. Then the ellipse can be constructed from its axes. The major axis of the required ellipse will be equal to the section of vertical trace P_V limited by the extreme elements of the cylinder; and the minor axis will be equal to the diameter of the cylinder base circle (see Part II, Geometrical Drawing).

An axonometric (isometric) projection of the truncated cylinder is constructed in the following way (Fig. 255*c*).

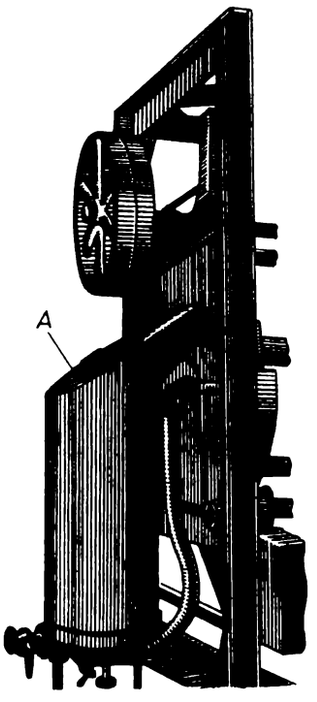


Fig. 256

First construct the right-hand base in isometry and draw the extreme elements. On the vertical diameter of the base circle, from the centre *o′* mark off the lengths *a*, *b*, etc., transferred from the profile projection of the cylinder. Then draw lines parallel to the cylinder axis and lay off on them the true lengths of the elements from the right base (transferred from the vertical projection). Finally, through the points thus obtained, draw straight lines parallel to the *o′y′*, and on them mark off lengths *3-7*, *2-8*, etc., transferred from the profile projection (see lengths *3″-7″*, *2″-8″*, etc., in Fig. 255*a*). Draw a smooth line through points *1*, *2*, *3*, *4*, etc., with the aid of a French curve.

An example from engineering is presented in Fig. 256, where the truncated cylinder is a part of the dust catcher of a machine for cleaning castings.

The flat lid *A* of the cylinder is inclined to its axis cutting a portion of an ellipse from it. The lower surface of the chute fitted at the top of the cylinder is a plane parallel to that of the lid and, consequently, intersects the cylindrical surface along a portion of a similar ellipse.

4. INTERSECTION OF A PLANE AND PYRAMID. DEVELOPMENT OF A PYRAMID

A right hexahedral pyramid (Fig. 257) with its base on the plane H is cut by a vertical projecting plane P.

As in the foregoing examples, the vertical projection of the section coincides with the vertical trace P_V of the cutting plane (Fig. 257*a*). The horizontal and profile projections of the section are constructed from points which are the points of intersection of the plane P and the edges of the pyramid. The true size of the section can be determined, for example, by using the coincidence method (the plane P together with the section contained in it is brought into coincidence with the horizontal plane of projection).

A complete development of the truncated pyramid is constructed in Fig. 257*b*.

First construct the developed surface of a non-truncated pyramid, where all faces, having the shape of a triangle, are equal and are constructed with the aid of a compass using the method of triangulation. The length of the base (the shorter side) of triangle *1-2-S* is equal to the side of the hexagon of the pyramid base. The length of the two longer sides is equal to the true length of an edge which can be determined using the profile projection of the pyramid (Fig. 257*a*). For instance, the length *s''-2''* or *s''-5''* is equal to R. Then from the vertex S lay off on the development the true lengths of the truncated edges, which are obtained in different ways: for two edges they can be transferred from the profile projection of the prism (the lengths *e''-5''* and *b''-2''*), the rest of them being determined by revolving the edges about the axis which is perpendicular to the plane H and passes through the vertex S on the vertical projection.

Join the points on the edges to obtain the developed side surface and attach the base and the section to complete the construction.

In constructing this pyramid in isometry (see Fig. 257*c*) begin with the base. Then on its plane construct in thin line the contour of the horizontal projection of the section (hexagon) using the method of coordinates.

Through the vertices of this hexagon draw vertical lines on which mark off the coordinates z of the intersection points which are transferred from the vertical or profile projection of

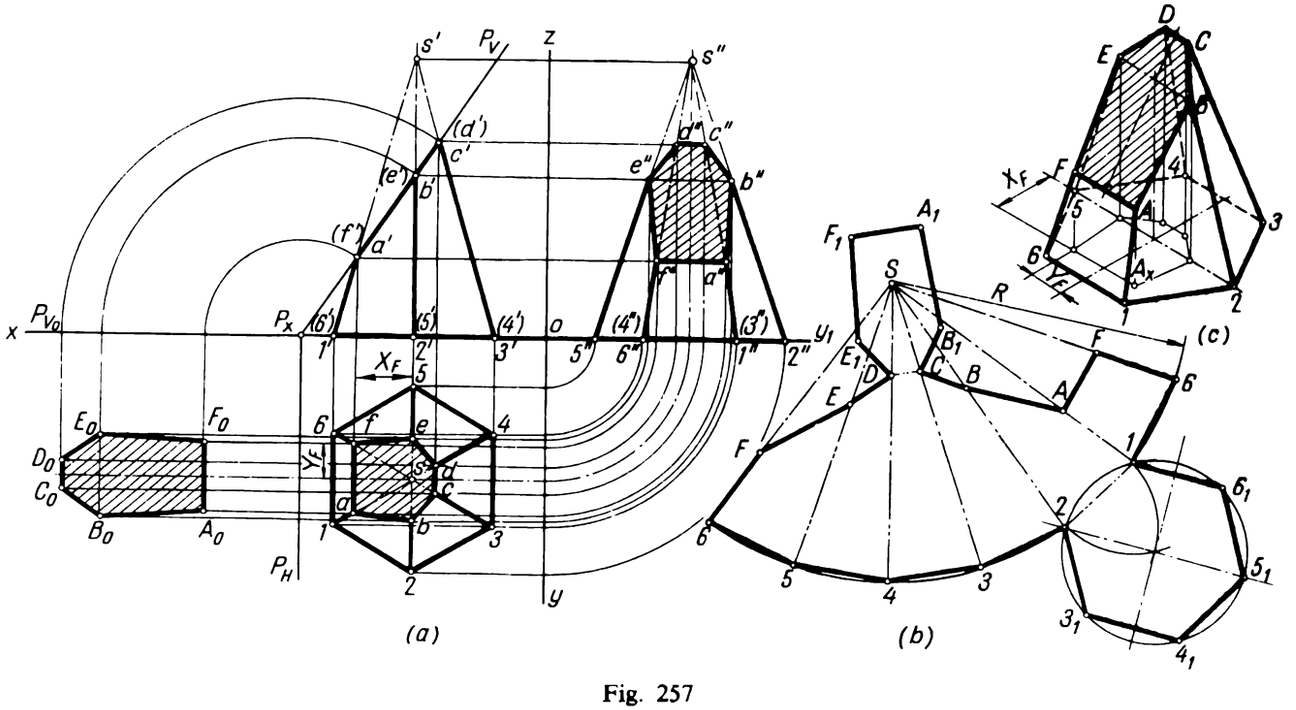


Fig. 257

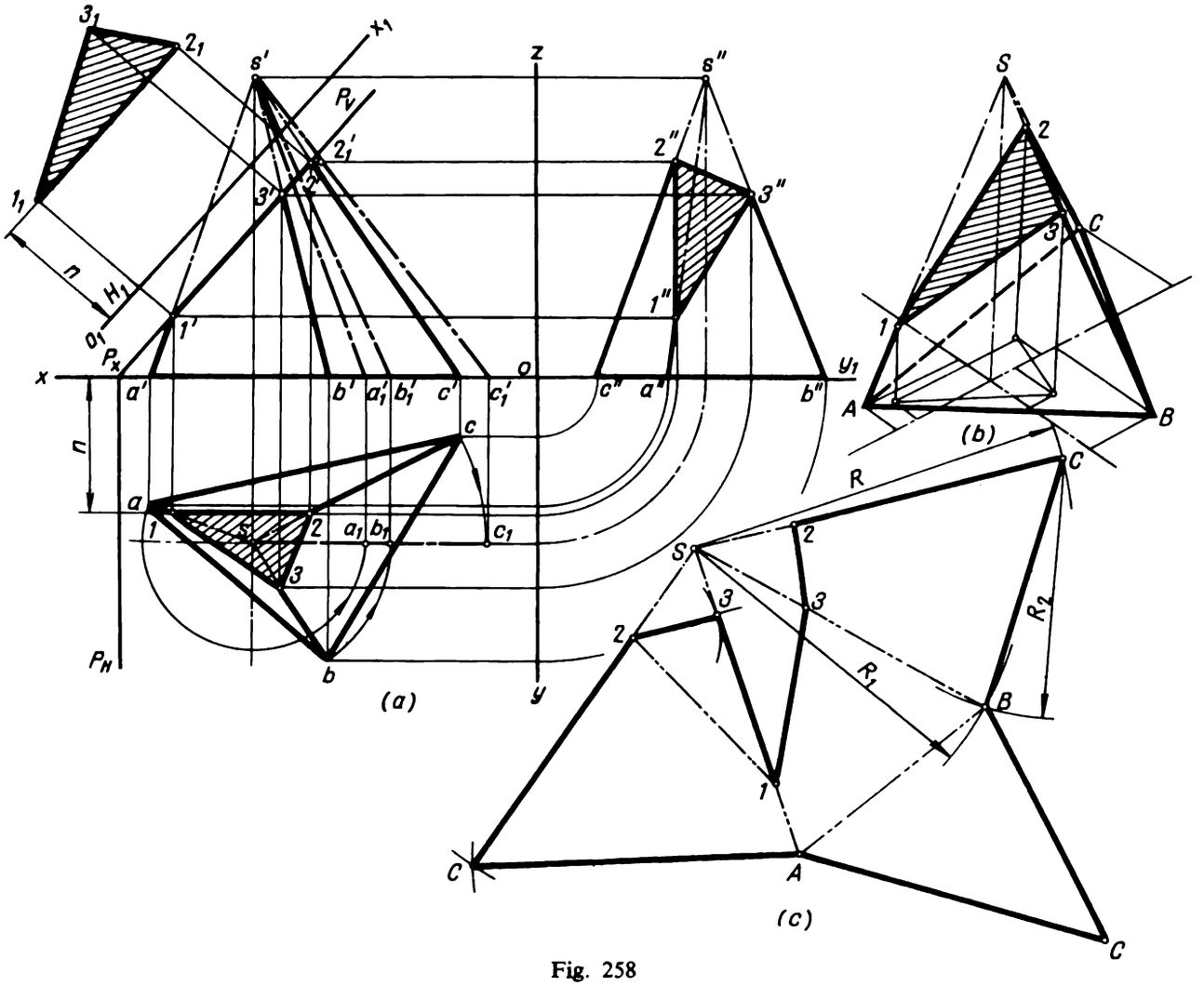


Fig. 258

the truncated pyramid. For instance, the coordinate z of the point A is marked off in isometry as the length A_xA.

An example of constructing three orthographic and one isometric projections of a non-regular trihedral pyramid cut by a vertical projecting plane P complete with the developed surface is illustrated in Fig. 258. The section is determined in the same manner as in the previous case, but its true image is constructed using the method of replacing projection planes. The horizontal plane of projection H is replaced with a new one with a new axis o_1x_1 which is parallel to the trace P_V (Fig. 258*a*). To construct the new horizontal projection of any point of the true image of the section (say, point *1*) lay off the distance *(n)* from the former horizontal projection of this point to the axis ox on the extension of the perpendicular to the new axis o_1x_1.

The true lengths of the truncated edges are found by revolving them about the vertical axis passing through the vertex s' on the vertical projection. For instance, the true length of the edge *2-C* is equal to the length $2'_1$-c'_1 obtained on the vertical projection after revolution.

This is how the developed side surface is constructed (Fig. 258*c*): first construct the development of the corresponding non-truncated pyramid for which purpose draw an arbitrary straight line and mark off on it the true length of the edge *SC*.

From the point *S* as a centre and with radius R_1 equal to the length of the edge *SB* describe

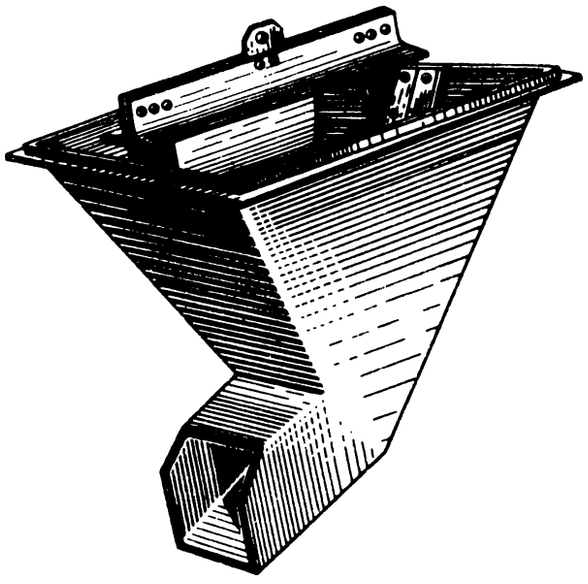


Fig. 259

an arc and from C as a centre and with radius R_2 equal to the side BC of the pyramid base draw another arc to intersect the first one at point B. Join B to S and C to obtain the true size of the face SBC. The rest of the faces are constructed in the same way. By laying off the true lengths of the remaining portions of the edges find points *1*, *2*, *3*, construct a development of the side surface of the truncated pyramid and attach to it the base and the triangle cut by the plane.

The isometric projection of this truncated pyramid (Fig. 258*b*) is constructed as in the previous case.

An example of practical application of a truncated tetrahedral pyramid is given in Fig. 259 showing a hopper made of steel sheets. It is cut at the bottom by a vertical projecting plane.

5. INTERSECTION OF A PLANE AND RIGHT CIRCULAR CONE. DEVELOPMENT OF A RIGHT CIRCULAR CONE

Different positions of a cutting plane with respect to the axis of a right-circular cone yield different conic sections.

Shown in Fig. 260 is a right circular cone with its base on the plane H cut by a horizontal projecting plane P which is parallel to its axis. In this case the section cut from the cone is a *hyperbola.**

The horizontal projection of the section is situated on the horizontal trace of the plane P (Fig. 260*a*), the vertical projection of the hyperbola being determined by a series of points. To find the vertical projection of a point on the hyperbola, say E, draw an auxiliary straight line, the cone element *S-12*, through the horizontal projection e of this point. Then determine the vertical projection of this element s'-*12*$'$ and, by projecting on it the point e, obtain the required projection e'. Having two projections of the point (e and e') it is easy to construct its profile projection e''. To construct the developed side surface of the cone divide the base circle into any number of equal parts (say, 12). Use the elements passing through the points of division of the circle for constructing the projections of the points lying on the hyperbola.

To determine the vertex of the hyperbola (point D) draw through S an auxiliary element perpendicular to the horizontal trace P_H of the plane. The required point is found on this element, which does not necessarily pass through a point of division of the circle.

The vertical and profile projections of the points on the hyperbola are joined with the aid of a French curve.

The true size of the section is found using the coincidence method: the plane P (together with the section contained in it) is brought into coincidence with the vertical plane of projection. To bring into coincidence any point on the hyperbola (say, point E) describe an arc from P_x as a centre and with a radius equal to $P_x e$ to intersect the axis ox. From the point of intersection erect a perpendicular to the axis and project the point e' horizontally on it. The point E_0 thus found will belong to the true image of the section.

Begin constructing the developed surface of the cone (Fig. 260*b*) by drawing an arc from an arbitrary point S as a centre and with a radius equal to the length of the cone elements. Divide the base circle of the horizontal projection into any number of equal parts (say, 12). Transfer them to the arc and join each one to the vertex S with a straight line (element). From S mark off on these lines the true lengths of the preserv-

* More precisely, one branch of a hyperbola, which has two identical branches.

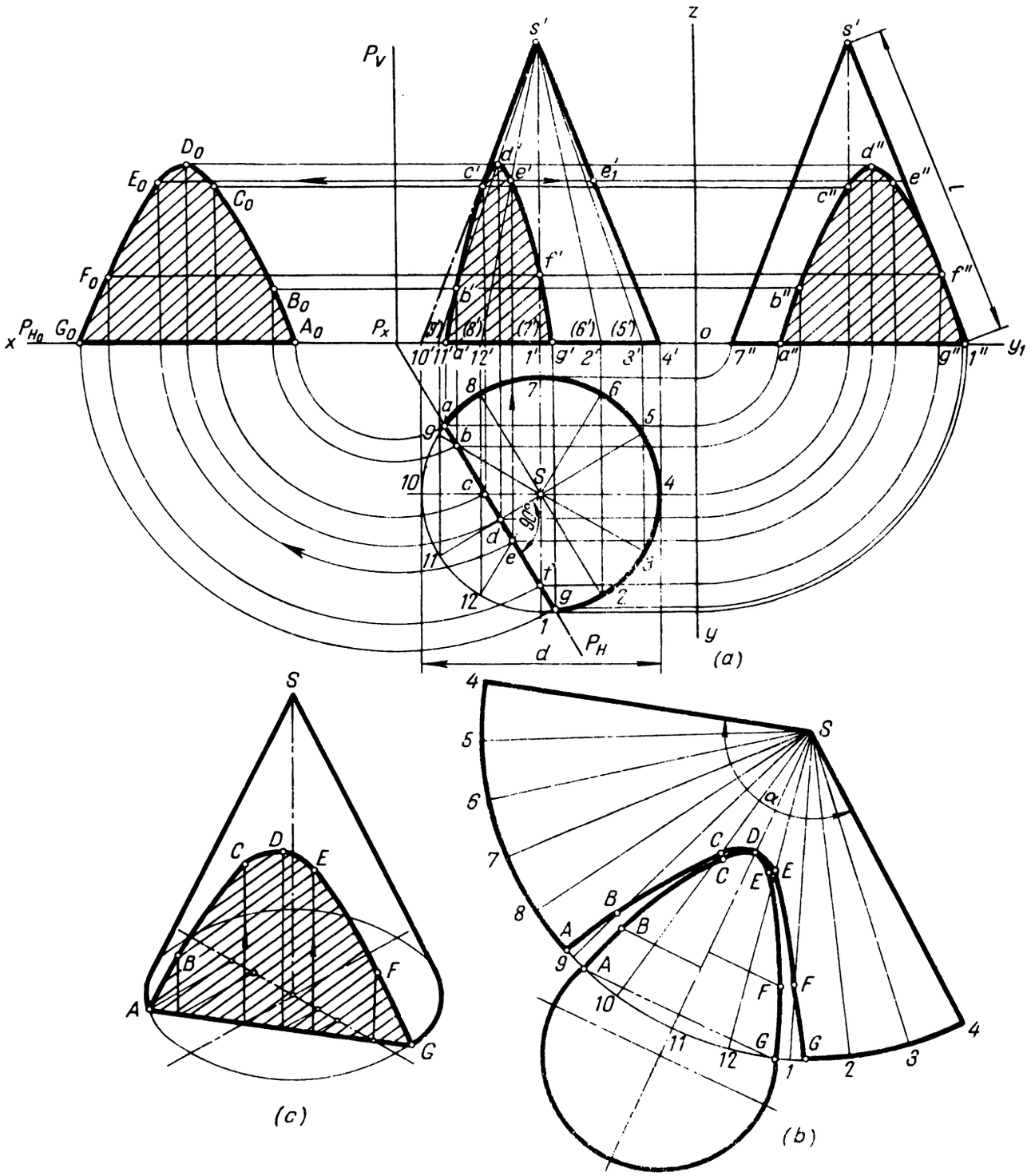


Fig. 260

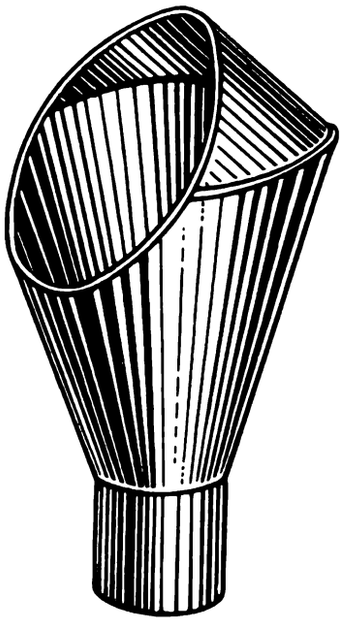


Fig. 261

ed elements. The true lengths of these elements can be determined by using any method. Here they are found by revolving the elements of the cone about its axis, which is perpendicular to the plane H, until they become parallel to the plane V. After the revolution this line is projected true size on the vertical plane of projection.

For instance, revolve the element $S\text{-}12$ until it is brought to a position parallel to the plane V; from the point e' draw a horizontal line to intersect the vertical projection of the extreme element at point e_1'. Then the line-segment $s'e_1'$ will be the true length of the line SE. This length should be transferred when constructing the developed surface of the cone.

Finally, attach the true size of the section and the base to complete the development.

To construct a more accurate development of a right circular cone the central angle α of the sector representing this development can be calculated using the formula

$$\alpha = 180\,\frac{d}{l}$$

where d = diameter of the base circle, mm
l = length of the cone element, mm

In constructing the isometric projection of a truncated cone (Fig. 260c) begin with the ellipse which represents the base of the cone. The isometric projections of any point of the hyperbola are conveniently constructed with the aid of its three coordinates, as is shown in the figure, the true coordinate lengths being transferred from the orthographic projections of the cone. The extreme elements of the cone are drawn through the vertex S and tangent to the base ellipse.

An example of practical application of a conic section is given in Fig. 261.

Shown in the figure is a separator cap welded from two cones made of thin steel sheets. At the left-hand side both cones are cut by a vertical projecting plane P inclined to the axes of the cones. In this case the plane cuts a hyperbola from the upper cone and an ellipse from the lower one.

6. DEVELOPMENT OF A SPHERE

A sphere can only be roughly approximated by development, since it is impossible to develop it on a plane without ruptures and folds.

In manufacturing various tanks, containers, jackets, etc., which are usually soldered or welded from metal sheets, approximate developments are quite satisfactory.

Given the orthographic projections of a sphere, its approximate development is constructed in the following way (Fig. 262).

1. Divide the sphere into several equal parts by a series of horizontal projecting planes Q_{H1}, Q_{H2}, etc., passing through the centre of the sphere (in Fig. 262a it is divided into eight sections, each section being referred to as a gore).

2. The spherical surface of each gore is then replaced with a cylindrical surface, whose axis passes through the centre of the sphere parallel to the line tangent to the equator.

3. Divide the sphere by a series of auxiliary horizontal planes (P, P_1, P_2, P_3, P_4, P_5, P_6) into eight parts of equal thickness. These planes will intersect the gores along arcs which are replaced with the elements of the corresponding cylindrical surface, i.e., with lines tangent to these arcs (Fig. 262a).

4. This is how a gore is developed (Fig. 262b):

(a) On a horizontal line AE mark off the length $1a = 1A$, then through its mid-point draw a vertical line and lay off on both sides of $1A$ a length equal to $\frac{\pi R}{2}$.

(b) Divide the length πR thus obtained into eight equal parts and, through the points of division, draw horizontal lines and mark off on

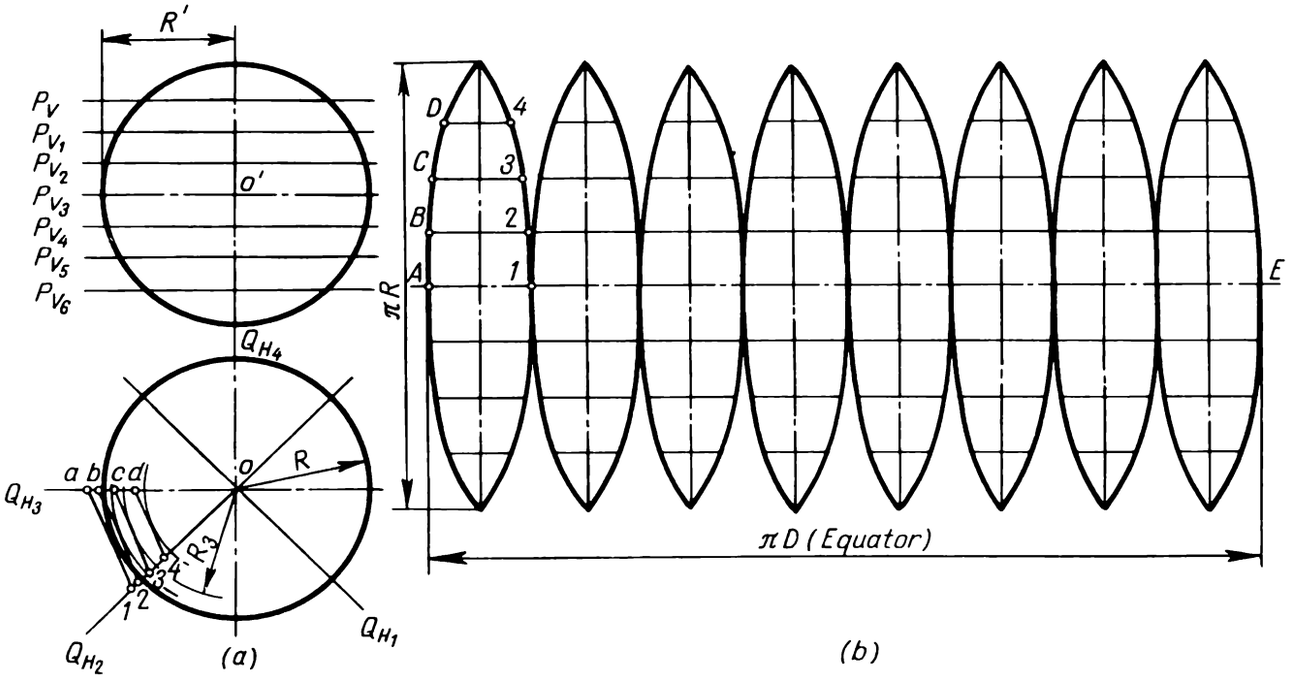


Fig. 262

them the true lengths of the tangent lines *2b*, *3c*, *4d*, i.e., the line-segments *2B*, *3C*, *4D*. Join the points thus found into a smooth curve.

The rest of the gores are developed in the same manner. The accuracy of a development will obviously depend upon the number of sections made. The greater the number of gores, the greater the accuracy of the surface development obtained.

Shown in Fig. 263*a* and *b* are welded containers with spherical surfaces.

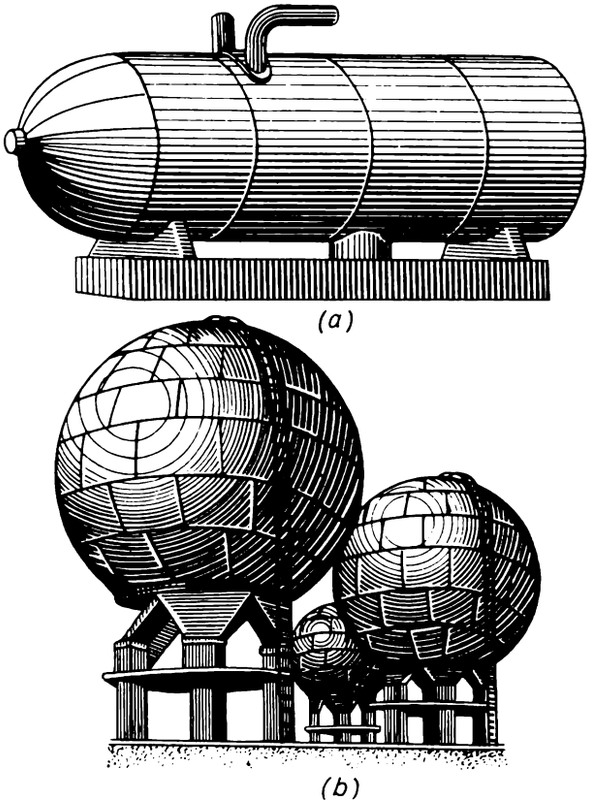


Fig. 263

7. LINES OF INTERSECTION

On drawings of massive parts (castings, forgings, etc.) it is often necessary to construct the projections of curved lines along which cutting planes intersect with various solids of revolution. Such curved lines are termed curves of intersection and are constructed from a series of points.

Consider the example illustrated in Fig. 264*a* presenting part of a hardness tester bounded by spherical, cylindrical, conic and flat surfaces. Here the curve of intersection is cut by a horizontal projecting plane. Another example is given in Fig. 265*a* presenting a connecting rod

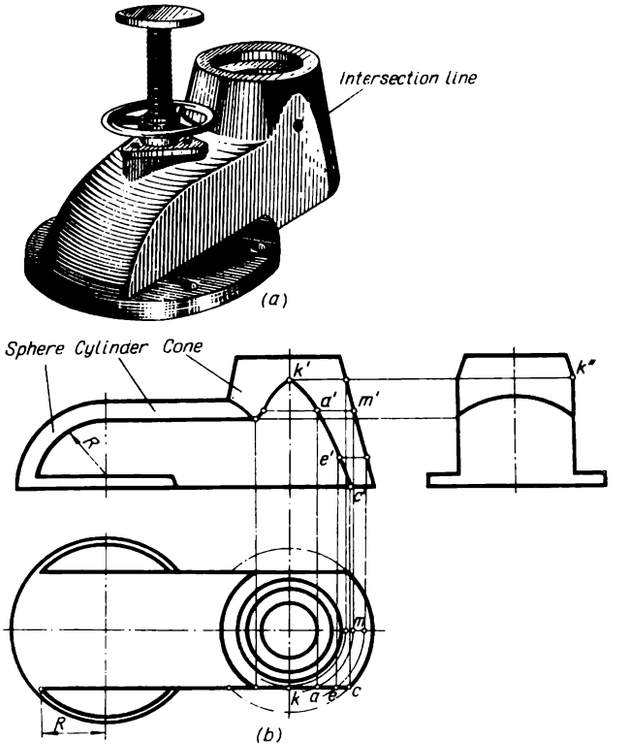


Fig. 264

end. In this case the curve of intersection is cut by a plane from a surface of revolution.

As is obvious from the drawings (Figs. 264*b* and 265*b*), the cutting plane in both cases is a vertical plane; hence the horizontal and profile projections of the curves of intersection coincide with the horizontal and profile traces of the cutting plane, respectively. Their vertical projections are constructed in the following way.

In the first case, where spherical, cylindrical and conic surfaces are cut (Fig. 264*b*), the line of intersection consists of three portions: the left-hand portion is an arc of radius R along which the cutting plane intersects with the spherical surface; the middle portion is a straight line (element of the cylinder), which is the line of intersection of the plane and the cylindrical surface; while the right-hand curve is a part of a hyperbola cut by the plane from the conic surface.

The hyperbola is constructed by determining its points with the aid of auxiliary circles located on the conic surface and drawn through the points belonging to the hyperbola. For instance, if such an auxiliary circle is drawn through the horizontal projection a of the point located on the hyperbola and the vertical projection of this circle is found (which is a horizontal line drawn through the point m' determined by projecting the point m in the vertical direction), then we can project on it the point a and find the required projection a'. The vertex k' of the hyperbola on the vertical projection is constructed by drawing on the plane H an auxiliary circle tangent to the horizontal trace of the cutting plane. The point c (c') lying on the base circle of the cone is the right-hand extreme point of the hyperbola.

In the second example (Fig. 265*b*) the vertical projections of the points belonging to the line of intersection are also constructed with the aid of auxiliary circles drawn in planes perpendicular to the axis of the surface of revolution and passing through the required points. For instance, if such a circle of radius R is drawn through point a'' on the plane W, then it is easy to find its vertical projection which is the vertical line $m'n'$. The required projection a' is

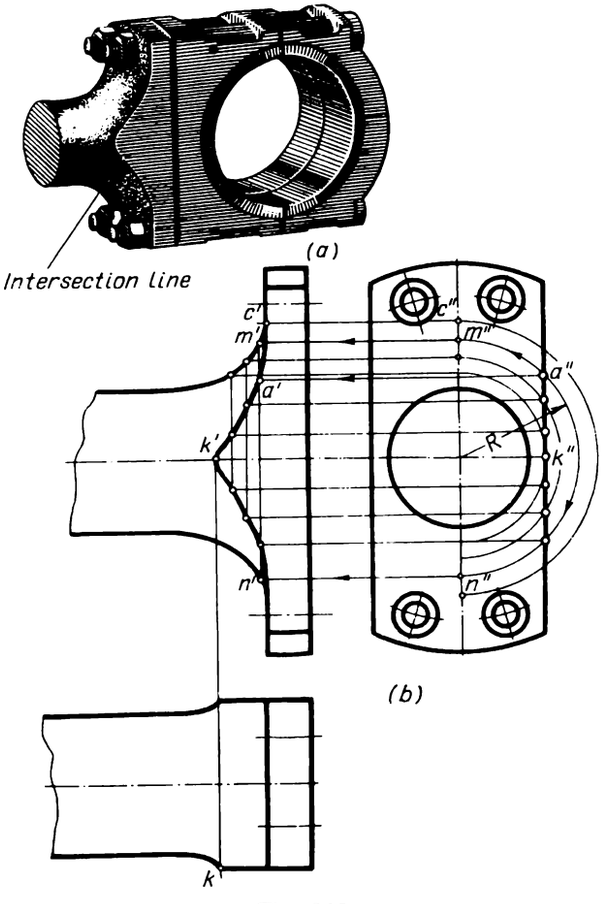


Fig. 265

constructed by projecting the point a'' in the horizontal direction.

Shown in Fig. 266 are machine elements with lines of intersection cut from them by different planes. The lower cylindrical part of the boring head (Fig. 266*a*) is cut by a plane inclined to the cylinder axis, the curve of intersection being a portion of an ellipse.

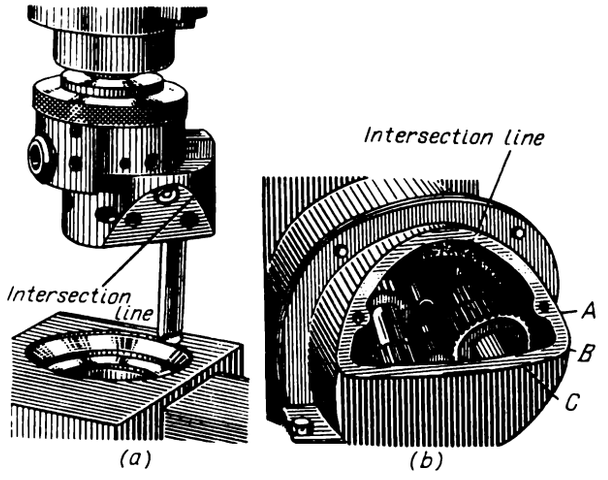


Fig. 266

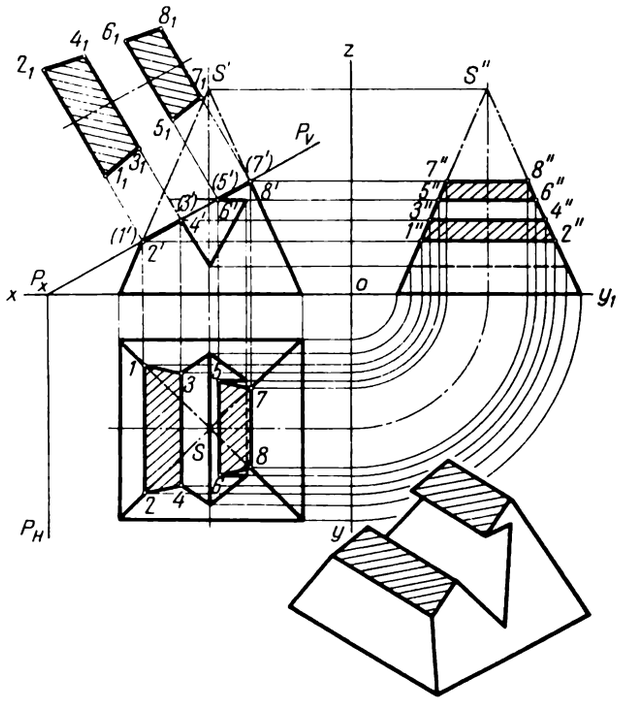


Fig. 267

The gear case of a machine tool (Fig. 266*b*) is bounded by a cylinder, a sphere, and a surface of revolution cut by a common plane; the curves of intersection thus obtained are *A*, *B*, and *C*, respectively.

Having mastered the construction of various geometrical surfaces and solids cut by various planes, as well as the methods of determining the true shape of appropriate sections and making developments of various surfaces, the student must do a number of exercises like the one presented in Fig. 267 to develop his spatial visualization. First construct three projections of the tetrahedral pyramid with a through hole. Then cut the pyramid with a vertical projecting plane *P* specified by its traces, construct the projections of the section (points *1* through *8*) and cross-hatch them.

Finally, determine the true shape of the section using one of the methods studied. In Fig. 267 the method of replacing projection planes is used for this purpose; the horizontal plane of projection H is replaced with a new plane H_1, the projection axis o_1x_1 coinciding with the trace P_V.

Questions

1. Give the definition of a section according to the USSR Standard and explain its purpose.
2. What method is employed in constructing the projections of sections cut by a projecting plane from a pyramid and a right circular cone?
3. How is the true shape of a section determined on a drawing?
4. What methods are used for making developments of a truncated pyramid and a right circular cone?
5. How are folding lines represented in developments?
6. What is the sequence in constructing an approximate development of a sphere?
7. What is the line of intersection and how is it constructed?

Exercise 52

Construct three projections of a cylinder cut by a plane; find the true shape of the section; make a development and construct an axonometric projection (Fig. 268*a*).

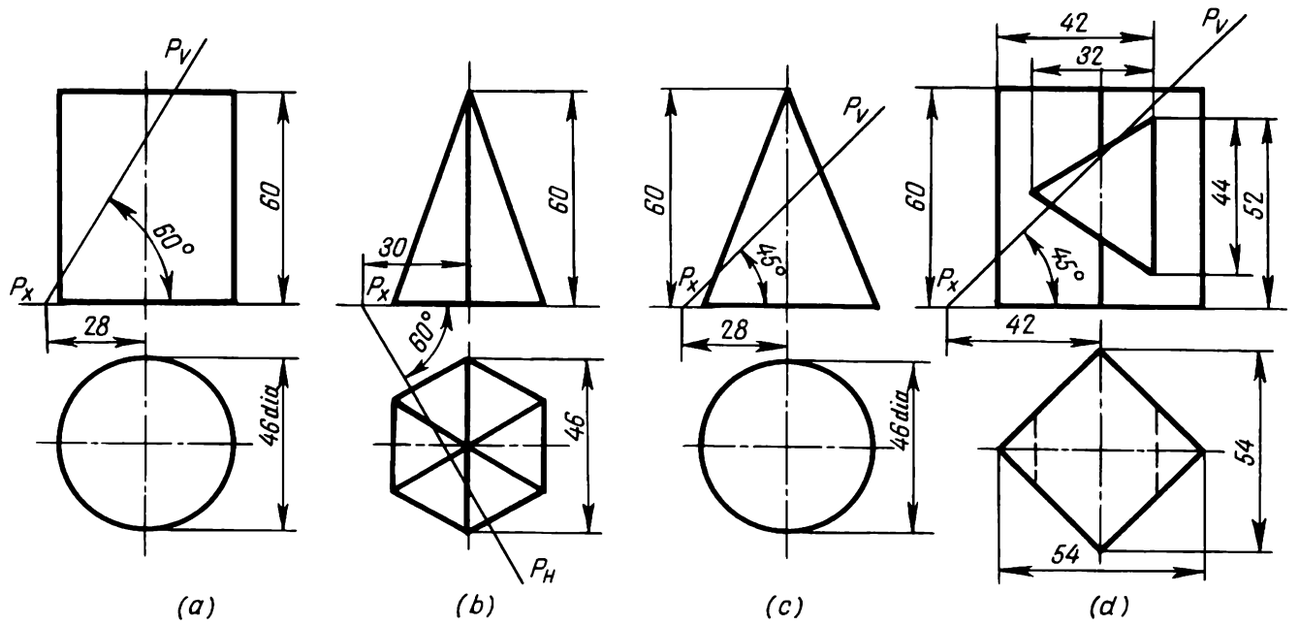


Fig. 268

Exercise 53

Construct three projections of a hexahedral pyramid cut by a plane; find the true shape of the section; make a development of the pyramid and construct its axonometric projection (Fig. 268*b*).

Exercise 54

Construct three projections of a cone cut by a plane; determine the true shape of the section; make a development of the cone and draw its axonometric projection (Fig. 268*c*).

Exercise 55

Draw a full-size vertical projection of the right tetrahedral prism with a through hole (Fig. 268*d*). Construct the section cut by plane *P* in the horizontal and profile projections. Find the true shape of the section.

CHAPTER 10

INTERSECTIONS OF SURFACES OF GEOMETRICAL SOLIDS

1. BASIC FACTS

Designers in many industries are constantly faced with problems involving intersections of surfaces of different solids. Boilers, smokestack breeching, ducts, ventilating devices, containers, tanks, machine casings, machine tools and other equipment are just a few examples. In ship, automotive, and aircraft drafting such problems are numerous and the intersections must be laid out full size.

The intersection of two surfaces is a line common to both surfaces. This line is often called a *transition line*. The process of finding this line consists in drawing elements of one surface and locating the points at which these elements pierce the other surface. An element of a surface is any line lying wholly in the surface. It may be either straight or curved.

The term *intersection of surfaces* usually refers to the more complicated lines that occur when such geometrical surfaces as cylinders, cones,

prisms, etc., intersect each other. Intersections of surfaces are often encountered in engineering drawing. Sometimes these lines are complicated irregular curves which are constructed from numerous points and require considerable accuracy.

2. INTERSECTIONS OF A STRAIGHT LINE WITH SURFACES OF GEOMETRICAL SOLIDS

Prior to constructing transition lines of surfaces it is essential to learn how to construct projections of points of intersection (points of entrance and exit) of a straight line with surfaces of various geometrical solids.

In all cases problems of this kind are solved as follows.

(1) Pass an auxiliary plane (usually a projecting one) through the given straight line. In the pictorial drawing of Fig. 269*a*, for example, an auxiliary horizontal projecting plane *P* is passed through the straight line *AB* piercing the pyramid.

(2) Find the lines of intersection of the plane *P* and the given surface (lines *KC* and *ED*).

(3) Determine the required points, *N* and *M*, of intersection of the lines thus found and the given straight line *AB*.

In the orthographic drawing (Fig. 269*b*) the projections of the intersection line are determined by the following method. The horizontal projections of the lines *KC* and *ED* coincide with the horizontal trace of the plane P_H. The vertical projections k', c', e', d' are found by projecting the points *k*, *c*, *e*, and *d* on the vertical projections of the bases. Join k' to c' and e' to d' with straight lines. The vertical projections of the required points are obtained as the points of intersection of these lines and the vertical projection $a'b'$ of the given line *AB*. The horizontal projections *n* and *m* of the intersection points are found by projecting the points obtained on the plane *H*.

In some specific cases one needs not use an auxiliary plane. For instance, the points of intersection of the line *AB* (Fig. 270) with the surface of the right circular cylinder are found in the following way.

The horizontal projection of the whole cylindrical surface is a circle, hence, the horizontal projections of all the points (including the intersection points *N* and *M*) on the cylindrical surface will lie on this circle.

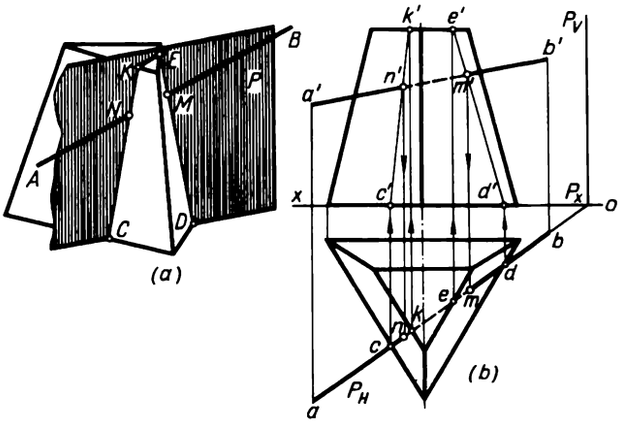


Fig. 269

The vertical projections n' and m' of the required points are determined by projecting *n* and *m* on the given vertical projection $a'b'$ of the line *AB*.

The problem is more complicated in the case of a right circular cone (Fig. 271). Through the line *AB* pass an auxiliary plane (but not a projecting one, since such a plane will cut a hyperbola from the cone), which must also pass through the vertex of the cone. This plane will intersect the cone along the elements SH_3 and SH_4 (Fig. 271*a*). In the orthographic drawing of Fig. 271*b* it is constructed as follows.

(1) Take a random point *K* on the given line *AB* and join it to the vertex of the cone with a straight line. The two intersecting straight lines *AB* and *SK* specify the plane *P*.

(2) Find the horizontal traces H_1 and H_2 of these two intersecting lines in a usual way.

(3) Join points h_1 and h_2 with a straight line to obtain the horizontal projection of the horizontal trace P_H, since the horizontal trace of the plane *P* will pass through the traces H_1 and H_2.

(4) The base of the cone is the horizontal trace of the conic surface. Therefore, having noted where this trace intersects with the trace P_H of the plane, we can find those two elements along which the conic surface is intersected by the auxiliary plane.

In the orthographic drawing (Fig. 271*b*) the ends of these elements are located at the points of intersection of the horizontal projection of the cone base (the circle) with the trace P_H, i.e., at the points h_3 and h_4. Join these points to the vertex *S*.

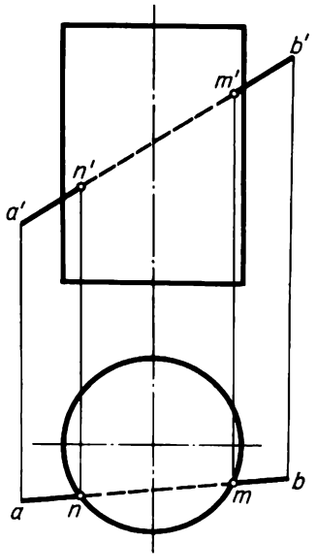


Fig. 270

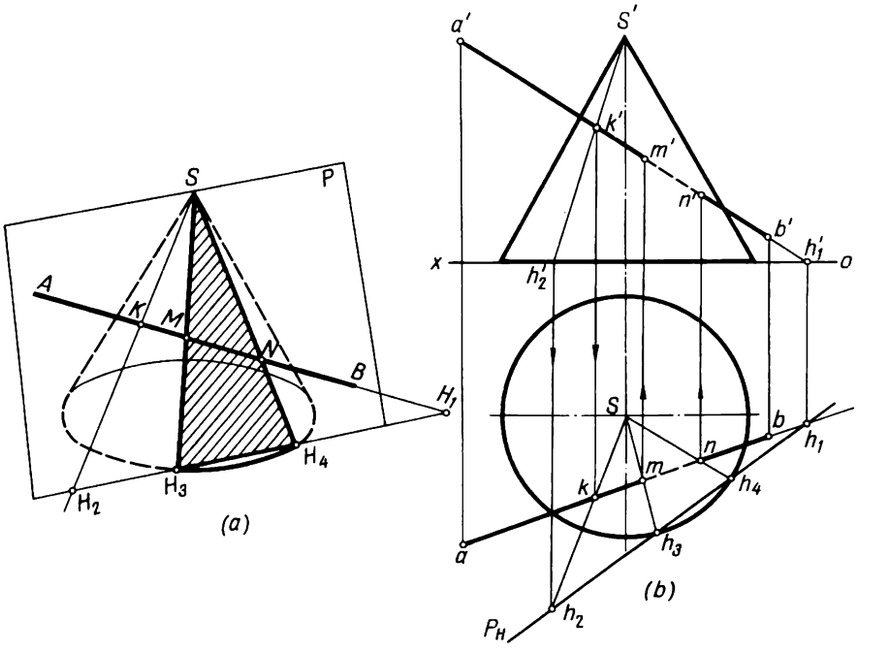


Fig. 271

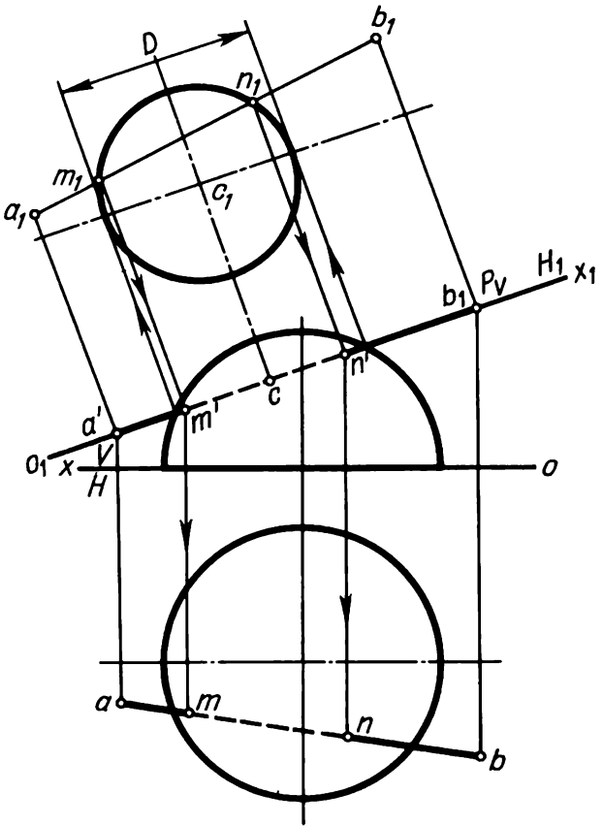


Fig. 272

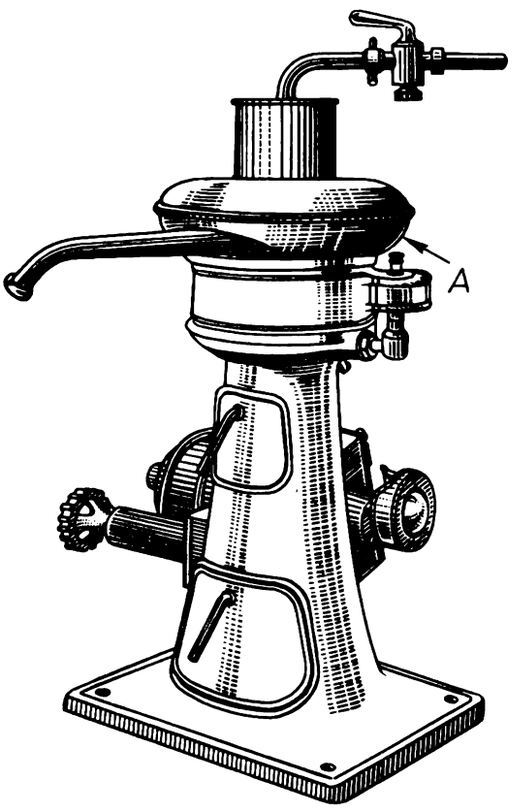


Fig. 273

(5) The required points M and N are found at the points of intersection of the elements found and the given line AB.

The horizontal projections m and n of the points of intersection are the points of intersection of the projections of the elements sh_3 and sh_4 with ab. Determine the vertical projections m' and n' by projecting m and n on the vertical plane of projection.

The points of intersection of line AB with a sphere (Fig. 272) can be found by passing through the given line AB an auxiliary vertical projecting plane P, which will cut a circle from the sphere.

Since the horizontal projection of this circle will be an ellipse, it is advisable to use the method of replacing projection planes, as otherwise the construction will be rather complicated. The new plane of projection must be chosen so as to be parallel to the auxiliary plane P, i.e., the new axis of projection o_1x_1 must be drawn so as to be parallel to the vertical projection $a'b'$ of the line AB. This is done for the sake of simplicity (in Fig. 272 the axis o_1x_1 is drawn through $a'b'$). Then construct the new horizontal projection a_1b_1 of AB and the new horizontal projection of the circle $\left(\text{radius } \frac{D}{2}\right)$ cut by the plane P from the sphere. The new horizontal projections of the two intersection points m_1 and n_1 lie at the points of intersection of the new horizontal projections. Determine the vertical (m' and n') and horizontal (m and n) projections of the intersection points by reverse construction.

A practical application is illustrated in Fig. 273.

Shown in the figure is a separator whose cap A has the surface of a torus. The cap is fitted with a tube of small diameter. It is necessary to determine the point of intersection of the geometrical axis of the tube with the cap's surface. This problem is solved by using an auxiliary horizontal plane passed through the geometrical axis of the tube.

The required point is found at the point of intersection of the tube's axis with the circle cut by the auxiliary horizontal plane from the torus.

3. GENERAL CONCEPTS

In constructing the projections of a transition line first find so-called *obvious points* which are determined without any constructions (for instance, points a' and b' in Fig. 274*b*). Then determine the *definitive points* located, for instance, on the extreme generatrices of surfaces of revolution (cylindrical, conic, etc.) or the extreme edges separating the visible portion of the transition line from the invisible. Such are the points c and d in Fig. 274*b* located on the edges of the upper (horizontal) face of the prism whose horizontal projection is visible.

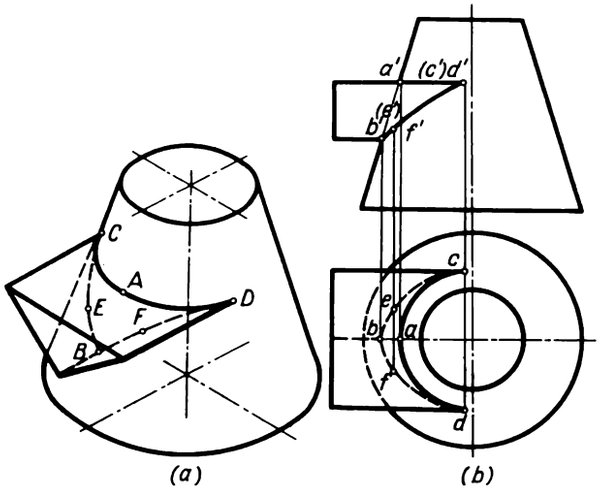


Fig. 274

Classified under definitive points are also the extreme points of an intersection line: upper, lower, right-hand, left-hand, and so on.

In the example under consideration such points are: the extreme right-hand points C and D and the left-hand point B; the upper points A, C, D and the lower point B, etc. (Fig. 274*a*).

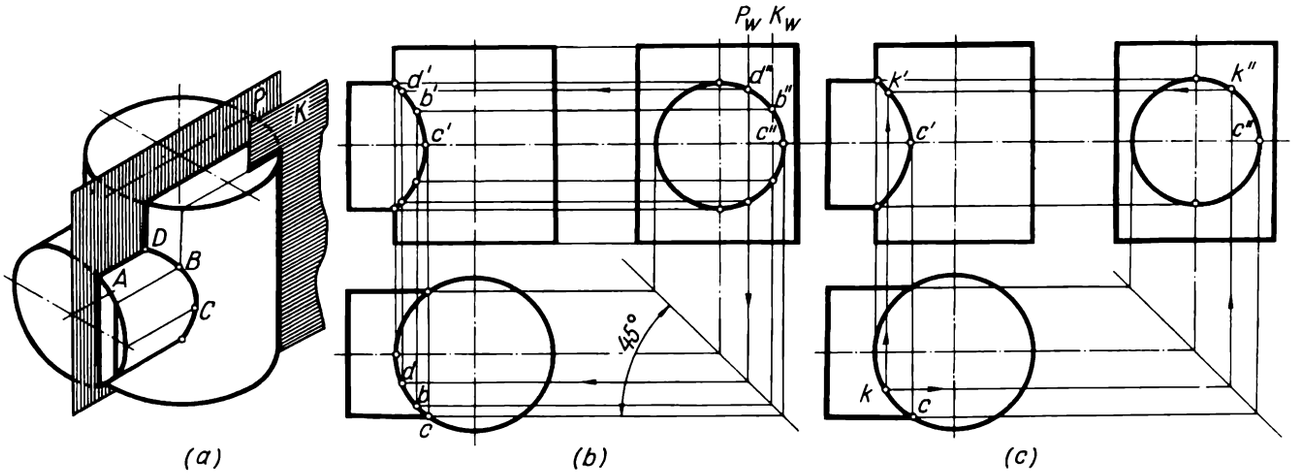
The rest of the points belonging to the line of intersection are called *intermediate points* (for instance, points E and F).

In the general case of constructing an intersection line use is commonly made of auxiliary parallel cutting planes or spherical surfaces.

The auxiliary planes used for the purpose should cut both given surfaces along simple lines — straight lines or circles, the latter being preferably situated in planes parallel to projection planes.

4. INTERSECTION OF CYLINDRICAL SURFACES

In making engineering drawings intersections of two cylindrical surfaces with the axes at right angles to each other are most frequent.



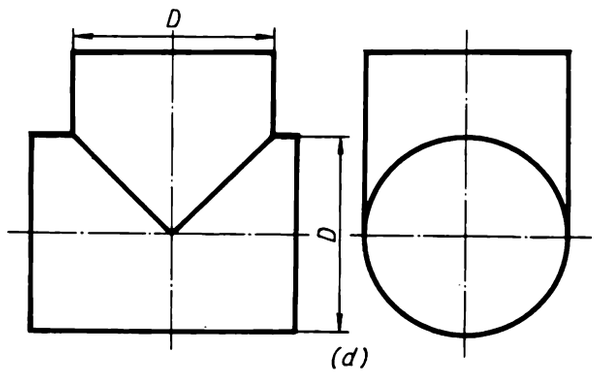


Fig. 275

Consider constructing two circular cylinders with the axes perpendicular to planes of projection (Fig. 275*a*).

In constructing orthographic projections of the intersecting cylinders use is made of the *non-axis method of projecting*, i.e., the drawing is free of the projection axes *ox*, *oy*, and *oz*. The absence of the axes makes the drawing more simple.

In this case the profile projections are conveniently constructed with the aid of a line at an angle of 45° to the horizontal as in Fig. 275*b*.

If we use the general method of constructing transition lines by means of auxiliary parallel planes intersecting both cylindrical surfaces along the generatrices, then the required points of the transition line will be the points of intersection of these generatrices (for instance, points *D* and *B* in Fig. 275*a*). But in the given example there is no need to make such a construction for the following reasons.

In this case one projection (the horizontal one) of the required intersection line coincides with the horizontal projection of the base of the larger cylinder, the other (the profile one) with the profile projection of the base of the smaller cylinder. Thus, the third projection (the vertical one) of the required line is easily found using the general rule for constructing a curved line from a series of points with the two projections of these points given. For example, taking the horizontal projection *k* on the required transition line (Fig. 275*c*) find the profile projection *k''*. Now, having the two projections, *k* and *k''*, determine the third projection *k'* (the arrows indicate the direction of construction).

The vertical projection of the line of intersection of two cylinders having equal diameters will represent two intersecting lines (Fig. 275*d*), which are the vertical projections of two semi-ellipses.

An example of mutual intersection of two cylindrical surfaces with the axes perpendicular to each other is illustrated in Fig. 276, where

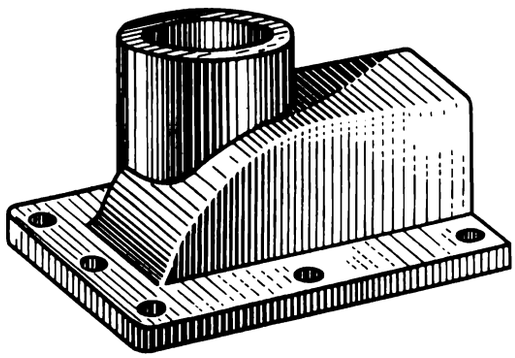


Fig. 276

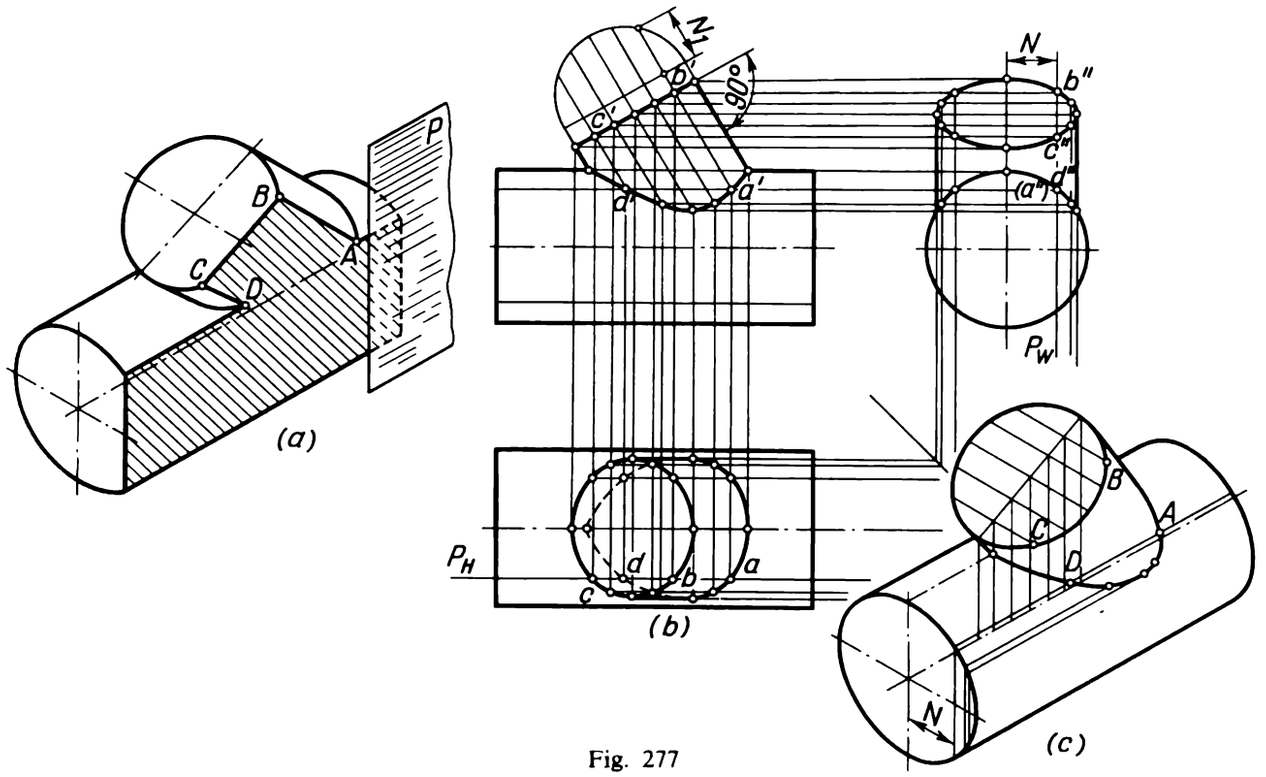


Fig. 277

one cylindrical surface of the machine part has a vertical axis, and the other (a quarter of a cylinder) has a horizontal one.

If intersecting cylindrical surfaces have the axes meeting at angles other than right angles, then their line of intersection is constructed with the aid of auxiliary parallel cutting planes or *spherical surfaces*.

Fig. 277 shows two such surfaces with the vertical and horizontal projections of the transition line constructed (the profile projection of this line coincides with the profile projection of the base circle of the larger cylinder).

To find the horizontal and vertical projections of a point A (Fig. 277*b*) on the transition line, the profile trace P_W of the auxiliary vertical plane P is drawn through the point a'', and the vertical projections ($a'b'$ and $c'd'$) of the two generatrices (AB and CD), along which the plane P cuts the smaller cylinder, are constructed. The corresponding generatrix of the larger cylinder can be found by drawing a horizontal line from the point a'', while that of the smaller cylinder is determined by projecting its terminal point B located on the base circle of the smaller cylinder.

Having the two projections a' and a'', the third (horizontal) projection a is found in the usual way. The generatrix of the smaller cylinder

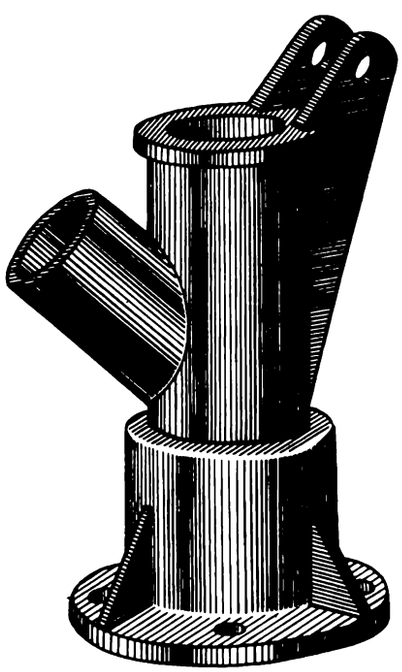


Fig. 278

can be determined more accurately by making use of an auxiliary projection of the semi-circle of the base of the smaller cylinder, i.e., by replacing the plane H with a new one, H_1, on which the base is projected true size. The lengths N_1 and N are equal.

The transition line can be obtained in isometry using either of the following two methods:

(1) constructing a series of points belonging to this line from their coordinates utilizing the given orthographic projection of the intersecting cylinders, or (2) constructing the line directly in isometry by drawing auxiliary parallel cutting planes parallel to the axes of both cylinders (Fig. 277*c*).

Shown in Fig. 278 is a machine component having two intersecting cylindrical surfaces with the axes at an acute angle to each other.

5. INTERSECTION OF PRISMS

Projections of lines of intersection of two right prisms are constructed in much the same way as those of two cylinders. If the faces and edges of two intersecting prisms are mutually perpendicular (Fig. 279*a*), then the intersection lines are constructed as in Fig. 275.

Prior to constructing an intersection line it is advisable to visualize its shape. In the case under consideration the horizontal and profile projections of the intersection line coincide with the horizontal projection of the pentagon (the base of one prism) and the profile projection of a portion of the quadrangle (the base of the other prism), respectively. The vertical projections of the broken line of intersection are constructed from the points of intersection of the edges of one prism with the faces of the other.

For instance, having the horizontal *(a)* and profile (a'') projections of the point A of intersection of the edge of the tetrahedral prism and the face of the pentahedral prism (Fig. 279*a*), it is easy to find the vertical projection (a') of this point.

An isometric projection of the line of intersection of the two prisms (Fig. 279*b*) can be constructed on the basis of the known orthographic projections of the points using their coordinates.

Pictured in Fig. 280 is a hydraulic pump whose casing has the shape of a right regular octahedral prism and intersects with hexahedral flanges (prisms). Since the edges of the prisms are mutually perpendicular, the principle of constructing the projections of the intersection lines is similar to that illustrated in Fig. 279*a*.

The lines of intersection of a trihedral prism and a trihedral pyramid (Fig. 281*a*) are also constructed from a series of points specifying the ends of line-segments forming the broken line of intersection. For example, the projections of the point A of the required line (Fig. 281*b*) are found in the following way. The ver-

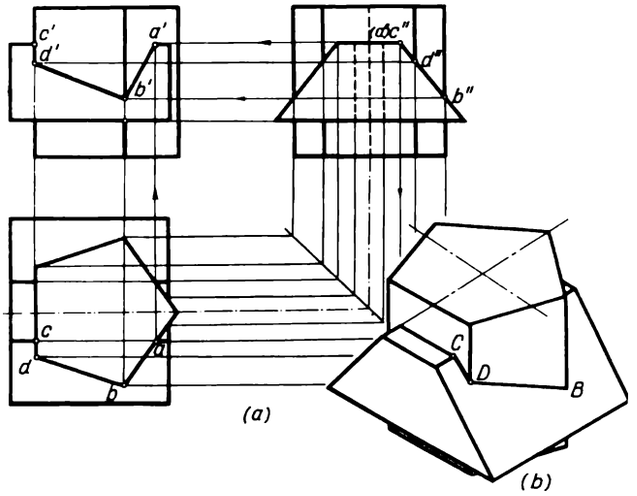


Fig. 279

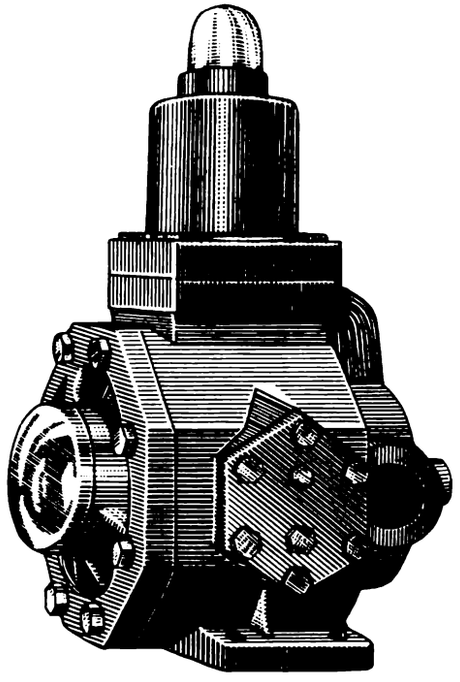


Fig. 280

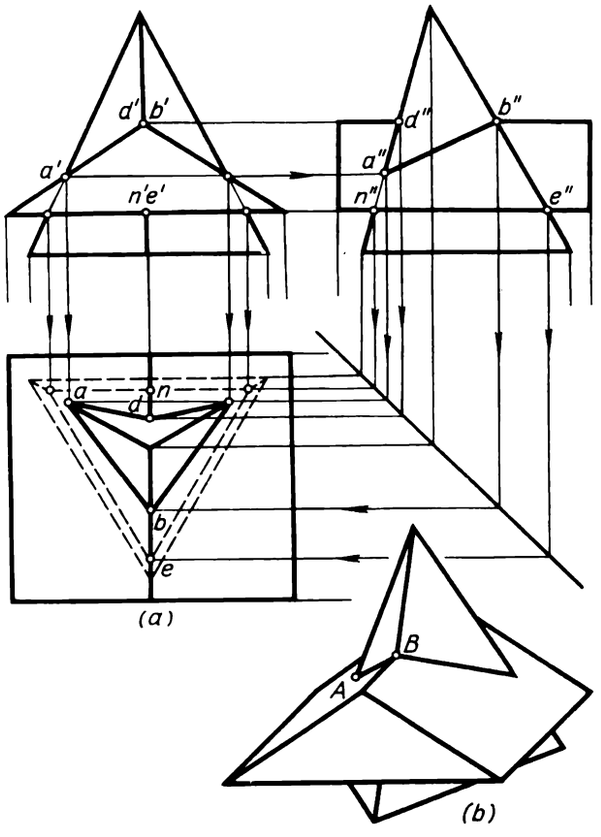


Fig. 281

tical projection a' is determined directly on the plane V, and the profile projection a'' is found by projecting the point a' on the profile projection of the appropriate edge of the pyramid. The horizontal projection is found in the usual way.

The projections of the point B located on the pyramid edge, which is a profile line, is determined by following the same procedure.

The axonometric projection of the transition line should be constructed from the coordinates of the points of intersection of the pyramid edges with the faces of the prism using the given orthographic projections of the intersecting solids.

Shown in Fig. 282 is a pictorial drawing of an optical comparator which has the shape of an irregular pentahedral prism with horizontal edges. It intersects with a tetrahedral pyramid for mounting the screen. The projections of the transition line common to the prism and pyramid are constructed from the points of intersection of the edges of the pyramid and the faces of the prism.

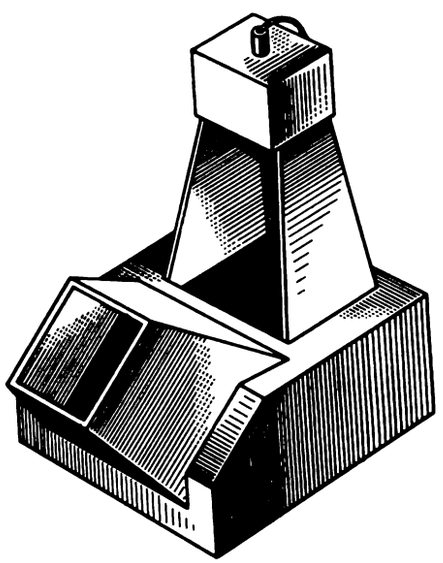


Fig. 282

6. INTERSECTION OF A CYLINDER AND A CONE

An example of constructing the line of intersection of a right circular truncated cone having a vertical axis and a horizontal cylinder, with their axes intersecting at point O_1, is given in Fig. 283.

First choose parallel auxiliary cutting planes. Do not take vertical or profile planes, as they will cut hyperbolas from the cone, which are too complicated. Horizontal planes are suitable here, since the lines of intersection will be circles for the cone and straight lines (generatrices) for the cylinder (see Fig. 283*a*). The required points of the line of intersection are found at the intersection of straight lines with circles (say, point *5*).

To determine the horizontal projection of point *5* (Fig. 283*b*), from the centre of the cone base and with radius R_5 draw the horizontal projection of the arc along which the auxiliary horizontal plane P_5 (P_{W5}) intersects the cone.

Since the profile projection *5″* of point *5* is known, find its horizontal projection *5* by projecting point *5″* on the obtained arc. Now, having two projections of the point, find the third one.

As is seen from the drawing, a portion of the horizontal projection of the intersection line is invisible. The demarcation points between the visible and invisible portions of the transition

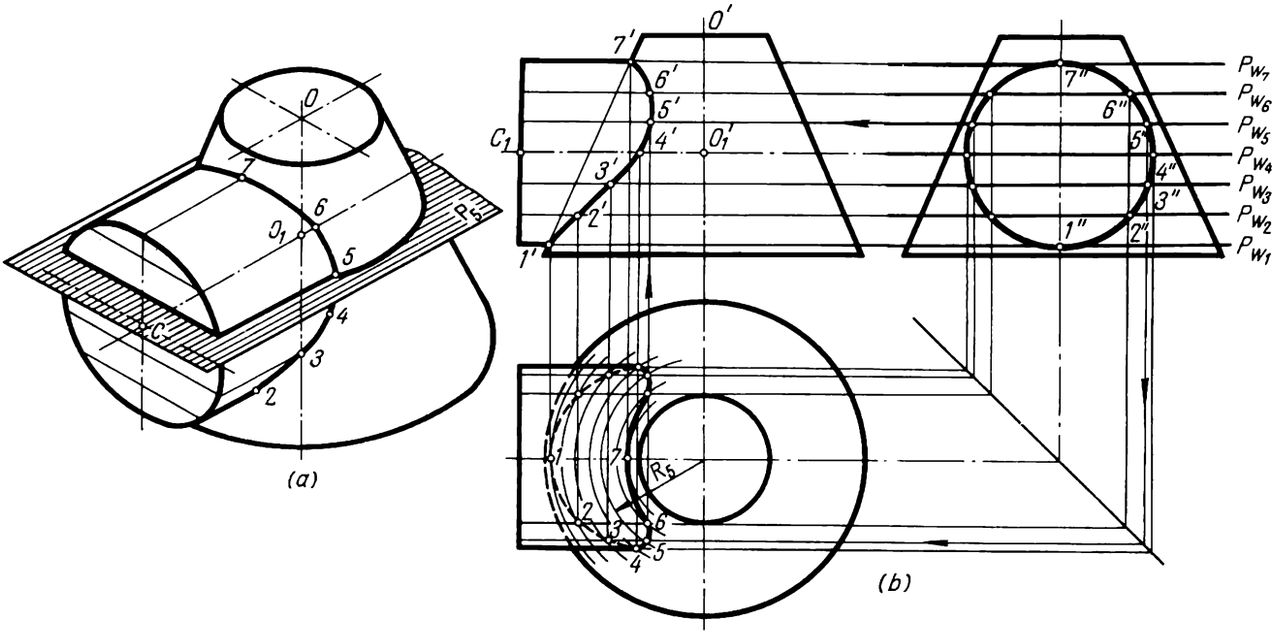


Fig. 283

line are determined with the aid of an auxiliary cutting plane P_4 passed through the axis of the cylinder (and through its extreme elements). The points located above the plane P_4 will be visible, and those below invisible.

To construct the pictorial drawing of the bearing casing shown in Fig. 284, use the above considered example.

If the geometrical axes of a cylinder and a cone do not intersect (say, they are parallel as in Fig. 285), the construction of the intersection line differs but little from the above method. The auxiliary cutting planes should be horizontal, for instance P and P_1 (P_V and P_{V1}), to cut circles from the cone and cylinder. The circles cut from the cylinder are of one and the same diameter D, while those cut from the cone are of different diameters. The horizontal projections of the required points on the intersection line are found at the intersection of the horizontal projections of the circles (points *1* to *7*). The vertical projections (*1′* to *7′*) of these points

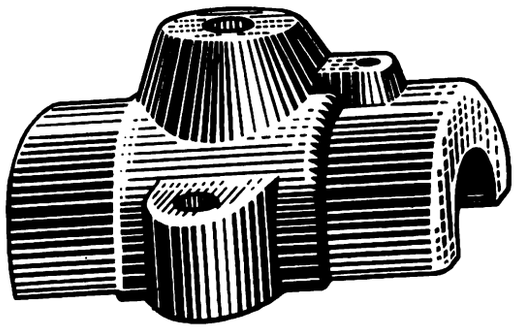


Fig. 284

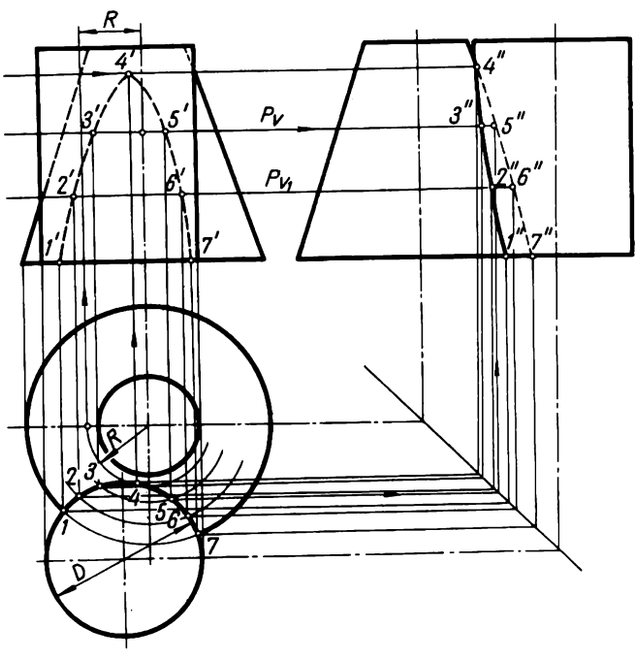


Fig. 285

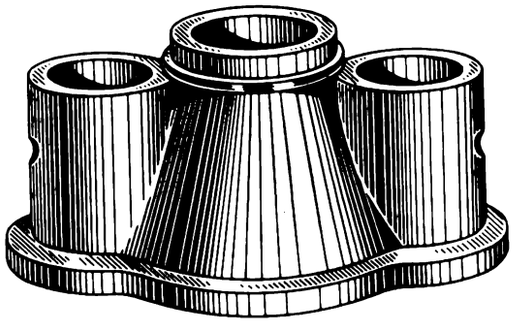


Fig. 286

are found on the vertical traces P_V and P_{V1} of the auxiliary cutting planes. The profile projections of the points are determined using their horizontal and vertical projections.

A definitive point in the given example is the highest point of the intersection line (point *4*). First find its horizontal projection bearing in mind that it is the closest point to the axis of the cone. Then find its vertical projection. To this end, describe an arc of radius *R* through the horizontal projection of point *4*, construct its vertical projection (which will be a horizontal straight line), and project on it the point *4*.

Fig. 286 shows a crosspiece which consists of two right circular cylinders intersecting with a right circular cone. The projections of the intersection lines can be constructed from a series of points which are found with the aid of auxiliary horizontal planes (see Fig. 285).

7. INTERSECTION OF A PRISM AND A SPHERE

An intersection of a right regular trihedral prism and a hemisphere is shown in Fig. 287*a*. In this example the horizontal projection of the intersection line (Fig. 287*b*) coincides with the horizontal projection of the side surface of the prism, i.e., with an equilateral triangle. The vertical projection of any point of the intersection line (say, point *B*) is determined with the aid of an auxiliary vertical plane. Such a plane (P_3) will intersect the face of the prism along the vertical line BB_1, and cut a semi-circle of radius *R* from the hemisphere (Fig. 287*a* and *b*).

The vertical projection b' of the point *B* is found at the intersection of the vertical projections of the line BB_1 and the circle of radius *R*. Now draw a smooth curve through the point b' and other points thus found and determine the visible and invisible portions of the line of intersection.

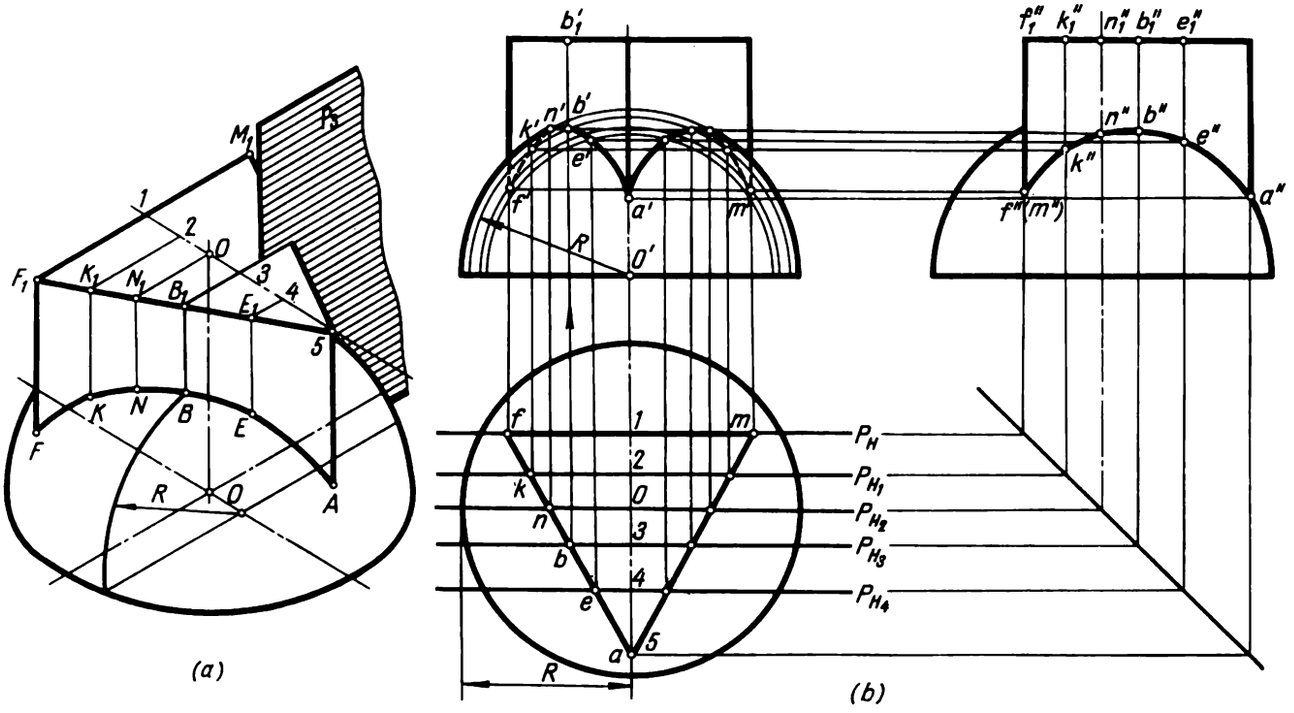


Fig. 287

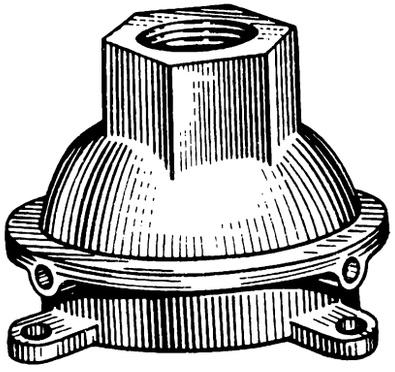


Fig. 288

The definitive points dividing the transition line into the visible and invisible parts are points N lying in the plane P_2 which passes through the centre of the sphere. The points found with the aid of auxiliary planes P_{H2} to P_{H4} will be visible.

The isometric projection of the intersection line can be constructed, as in many previous cases, by the method of determining a series of points on the required line (Fig. 287*a*). Each point should be constructed from its coordinates transferred from the orthographic drawing, the origin of the coordinates being taken at the centre of the sphere. Begin constructing the isometric pictorial drawing with the base of the hemisphere, which will be an ellipse, followed by the upper base of the prism, i.e., by a triangle. Then draw an axis of symmetry of the triangle (line *5-1*) and mark off on it line-segments *0-2*, *0-1*, *0-3*, *0-4*, *0-5* equal to the lengths of their horizontal projections. Through points *1*, *2*, *0*, *3* draw lines parallel to F_1M_1, and from the points K_1, N_1, B_1, and E_1 draw vertical lines transferring the lengths of these line-segments from the profile (or vertical) projection (for instance, line-segment $B_1B=b_1'b'=b_1''b''$).

A practical application of such a construction is shown in Fig. 288 presenting a pump lid which has the shape of a right regular hexahedral prism and a hemisphere intersecting each other. The procedure of constructing the intersection line is similar to that of the foregoing example. In this case profile planes (parallel to the plane W) may be taken as auxiliary cutting planes instead of vertical ones. First determine the profile projections of the points on the intersection line. Then construct their vertical projections from the horizontal and profile projections.

8. INTERSECTION OF A SPHERE AND A CYLINDER

Consider a right circular cylinder intersecting a sphere whose centre is located on the cylinder's axis (see Fig. 289*a*). The intersection line will be a circle, its vertical projection being a straight line. Pass an auxiliary horizontal plane P through points A and B of intersection of the extreme generatrices of the cylinder with the sphere. This plane will intersect both the cylinder and the sphere along one and the same circle contained in it. Consequently, the vertical projection of this circle will be the line-segment $a'b'$.

The same intersection line (a circle) will result from an intersection of a sphere and a cone or any other surface of revolution.

Shown in Fig. 289*b* is a branch pipe whose lower part is bounded by a spherical surface.

If the centre of the sphere is not on the cylinder axis (as in Fig. 290*a*), then the intersection line can be constructed using a number of auxiliary horizontal planes (Fig. 290*b*). Thus, the auxiliary horizontal plane P will cut a circle of radius r from the cylinder, and a circle of radius R from the sphere. The intersection of these circles gives the required horizontal projections a and b of the points on the intersection line. Then the vertical projections are constructed.

One of the definitive points of this intersection line is the highest point D. Its horizontal projection is found at the intersection of the line connecting the centres of the intersecting

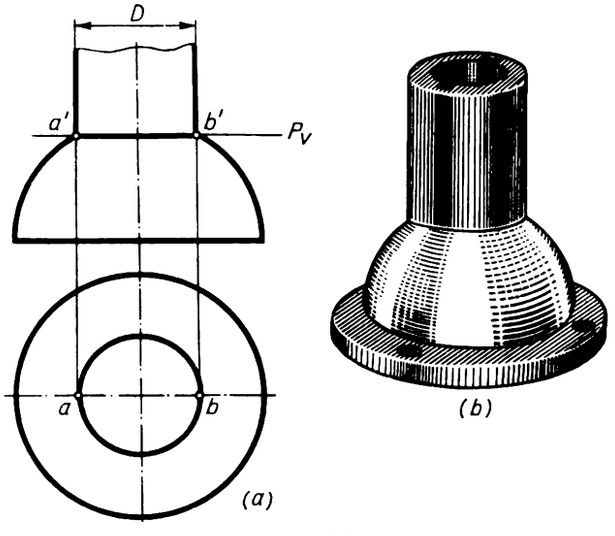


Fig. 289

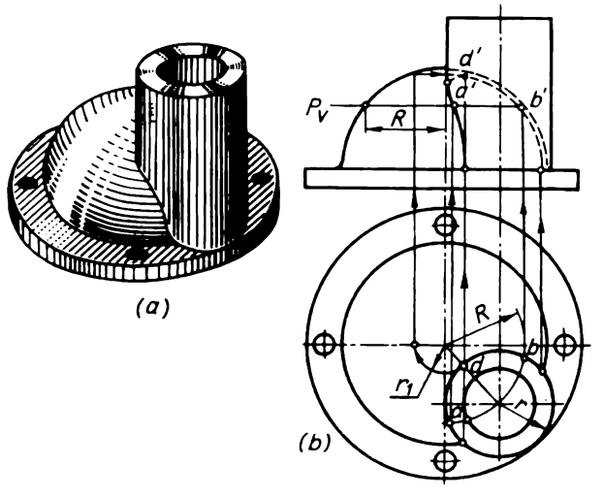


Fig. 290

surfaces and the circle of the cylinder base. To construct its vertical projection draw an arc of radius r_1 through the point d (as shown in Fig. 290*b*), determine the vertical projection of this arc (a line-segment parallel to the axis ox), and project the point d on it.

9. INTERSECTION OF A TORUS AND A CYLINDER

Shown in Fig. 291*b* is a branch pipe illustrating the intersection of a torus and a cylinder. Its orthographic drawing (with the flanges removed) is presented in Fig. 291*a*.

The intersection line is constructed here with the aid of auxiliary vertical planes *K*, *N*, and *M*.

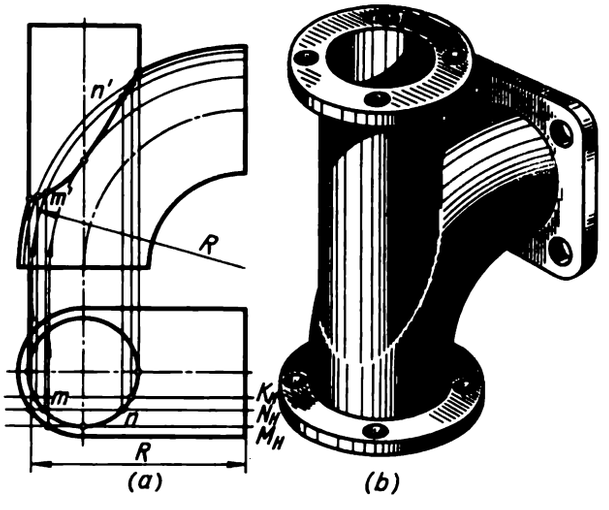


Fig. 291

For instance, the vertical plane *N* intersects the torus along a circle of radius *R*, and the cylinder, along two generatrices: *n* (*n'*) and *m* (*m'*). The intersection of these two elements and the circle of radius *R* on the vertical projection locates two points belonging to the required intersection line.

10. CONSTRUCTING INTERSECTION LINES BY SPHERES

In constructing intersection lines sometimes it is convenient to resort to auxiliary spheres instead of planes.

If two solids (say, cones *I* and *II* in Fig. 292*a*) intersect with one another and a third one (say, sphere *III*), then the lines of intersection of each of them with the third one will be plane curves. The two plane curves intersect with the straight line which joins their intersection points.

For example, in Fig. 292*a* the two lines of intersection of cones *I* and *II* with sphere *III* are circles lying in planes perpendicular to the vertical projection plane (in vertical projecting planes). These circles intersect at points *P* and *Q* which are to be connected with a straight line. The curved line of intersection of the two cones (with each other) passes through points *P* and *Q*, and is represented in the drawing as a straight line which is the vertical projection of an ellipse.

Consider a similar example, in which mutually intersecting solids are two right circular cylinders of equal diameters with the axes intersecting at point *O* (Fig. 292*b*). Suppose a sphere with the centre at the point *O* is inscribed in them, then the vertical projection of the sphere will be a circle tangent to the extreme elements of the cylinders. The lines of intersection of these

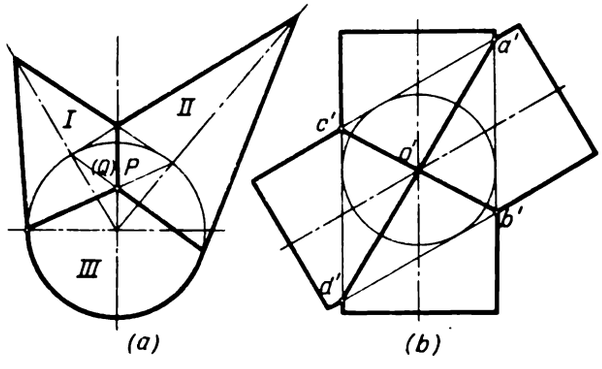


Fig. 292

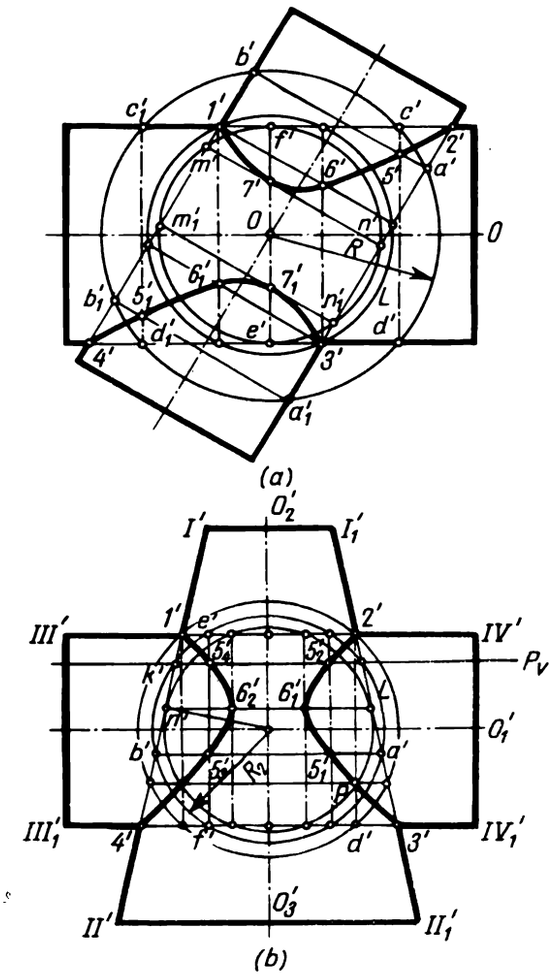


Fig. 293

cylinders will be two ellipses whose frontal, projections are represented by broken lines $a'o'b'$ and $c'o'd'$.

Auxiliary spheres can be used for constructing intersection lines, provided the following conditions are observed:

(1) The intersecting surfaces must be surfaces of revolution.

(2) The axes of the surfaces of revolution must intersect, their point of intersection serving as the centre of the auxiliary spheres.

(3) The axes of the intersecting surfaces of revolution must be parallel to a projection plane.

An example of using auxiliary spheres is given in Fig. 293*a* and *b*. Fig. 293*a* shows the construction of the transition line for two cylinders whose axes intersect at an acute angle at point *O*. Auxiliary concentric circles are described from the point *O*. Let us find, for instance, an intermediate point *5* belonging to the transition line.

1. From the point *O* as a centre and with radius *R* draw a circle representing the appropriate projection of an auxiliary sphere of the same radius, which will intersect the horizontal cylinder along a circle of diameter *CD* (line-segment $c'd'$ on the projection), and the inclined cylinder, along a circle of diameter *AB* (line-segment $a'b'$ on the projection).

2. The required point *5* is found at the point of intersection of the two obtained circles. On the vertical projection, point $5'$ is determined as the point of intersection of $a'b'$ and $c'd'$.

Introducing a series of auxiliary spheres we can construct a sufficient number of points on the intersection line. The range of radii of auxiliary spheres is determined in the following way:

(a) The maximum radius should be somewhat smaller than the distance between the point *O* and the most distant point of intersection of the extreme elements of the given surfaces (in Fig. 293*a* the distance between *O* and $2'$ (or $4'$); in Fig. 293*b* between *O* and $3'$ (or $4'$).

The minimum radius should be equal to the distance between *O* and the most distant extreme element. Thus, an auxiliary sphere with the minimum radius must be tangent to one of the intersecting surfaces. For instance, the definitive point *7* on the intersection line can be obtained with the aid of a sphere whose diameter is equal to that of the horizontal cylinder.

In machine building frequent use is made of parts having various lines of intersection. Here are some examples:

(1) Shown in Fig. 294*a* is a hardness tester. At the bottom we see the line of intersection of a pyramid and a sphere.

(2) Fig. 294*b* presents the carriage of a turret lathe with two mutually intersecting conic surfaces.

(3) The casing and cover of the mixer shown in Fig. 294*c* have abundant intersection lines.

(4) The pump illustrated in Fig. 294*d* incorporates two intersecting cylinders and a prism intersecting a cylinder.

Maximum accuracy is required in constructing projections of intersection lines for parts made of sheet metal, since a developed surface is needed for their manufacture.

Illustrated in Fig. 294*e* is an installation designed for preparing foundry sand. Here the

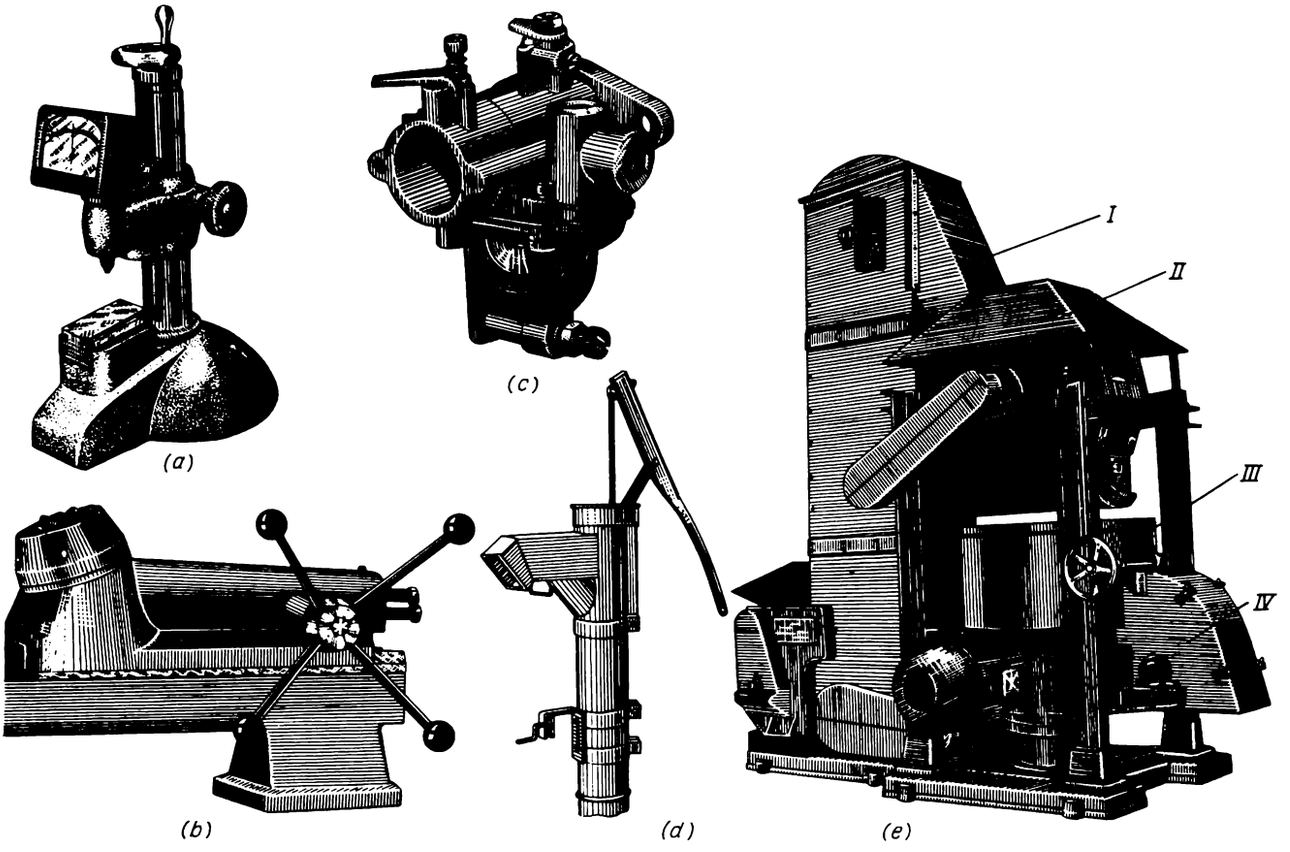


Fig. 294

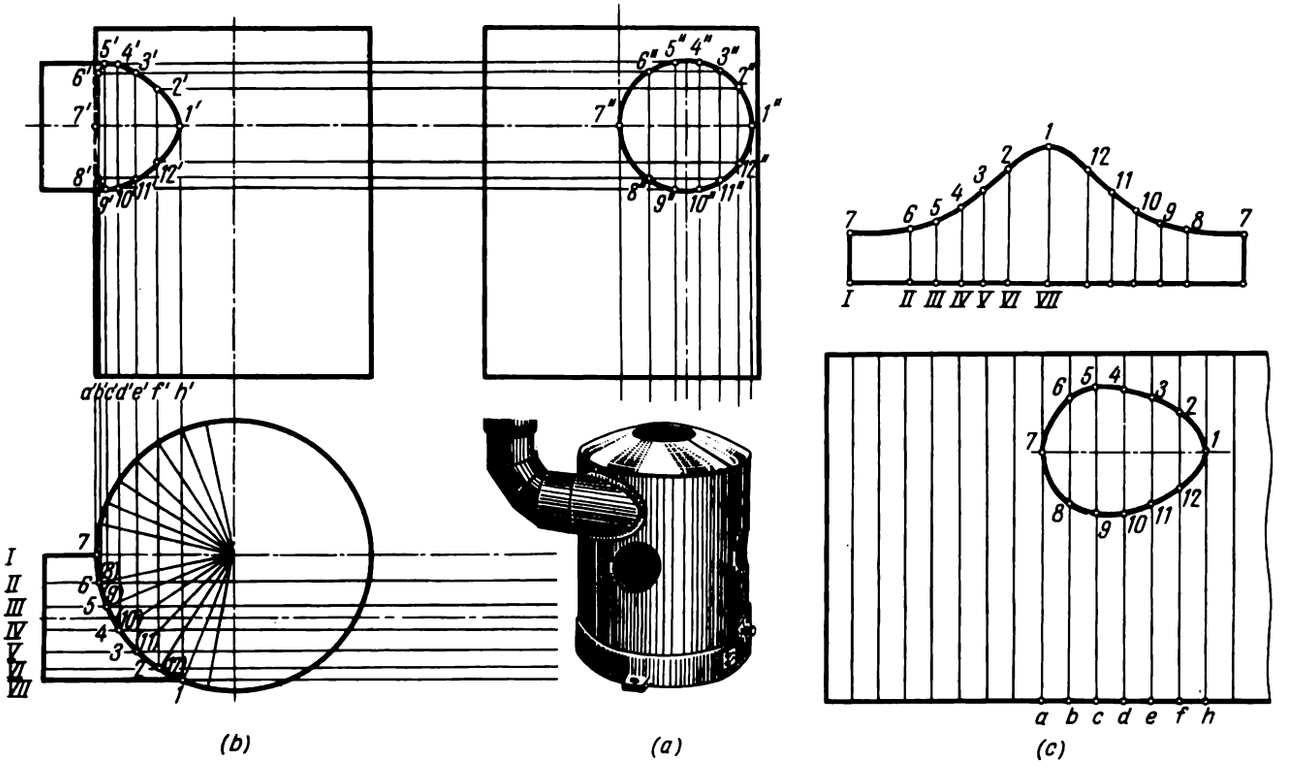


Fig. 295

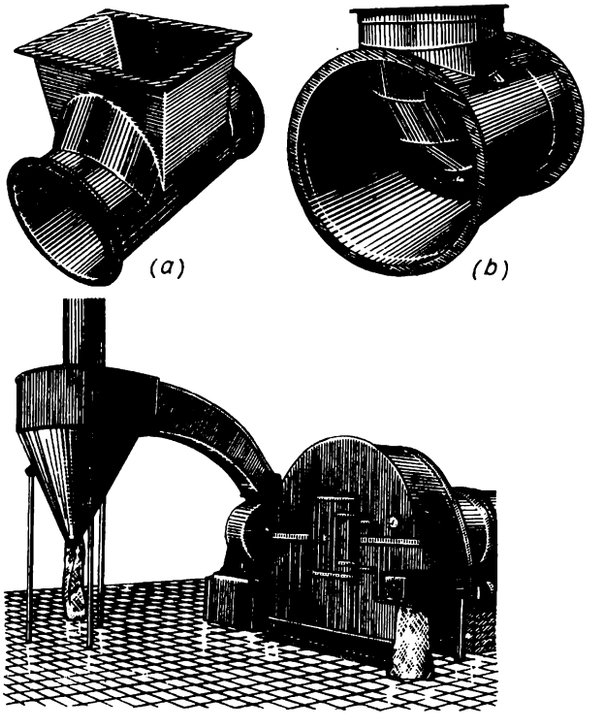


Fig. 296

pyramid-shaped hood *II* intersects prism *I*, and cylinder *IV* intersects cylinder *III*.

The dust collector shown in Fig. 295*a* has the shape of a right circular cylinder intersected by another cylinder (the branch pipe). The line of intersection of these cylinders is constructed in Fig. 295*b*, Fig. 295*c* presenting their developed surfaces.

The hopper shown in Fig. 296*a* is bounded by a cylindrical surface intersecting with the surfaces of a truncated pyramid and a cone.

The branch pipe in Fig. 296*b* has a conic surface intersecting with a solid bounded by a number of cylindrical surfaces.

The upper portion of the casing of the cyclone shown in Fig. 296*c* represents a cylinder intersecting with a side duct of prismatic shape.

In all these practical examples the projections of the intersection lines and developments are constructed following the procedure considered in the previous cases.

Questions

1. Define the intersection line. What is the general principle of constructing it on an orthographic drawing?
2. How is the point of intersection of a straight line with a right circular cylinder and with a right circular cone having vertical axes determined?
3. In what cases can the line of intersection of two right circular cylinders be constructed without using auxiliary cutting planes?

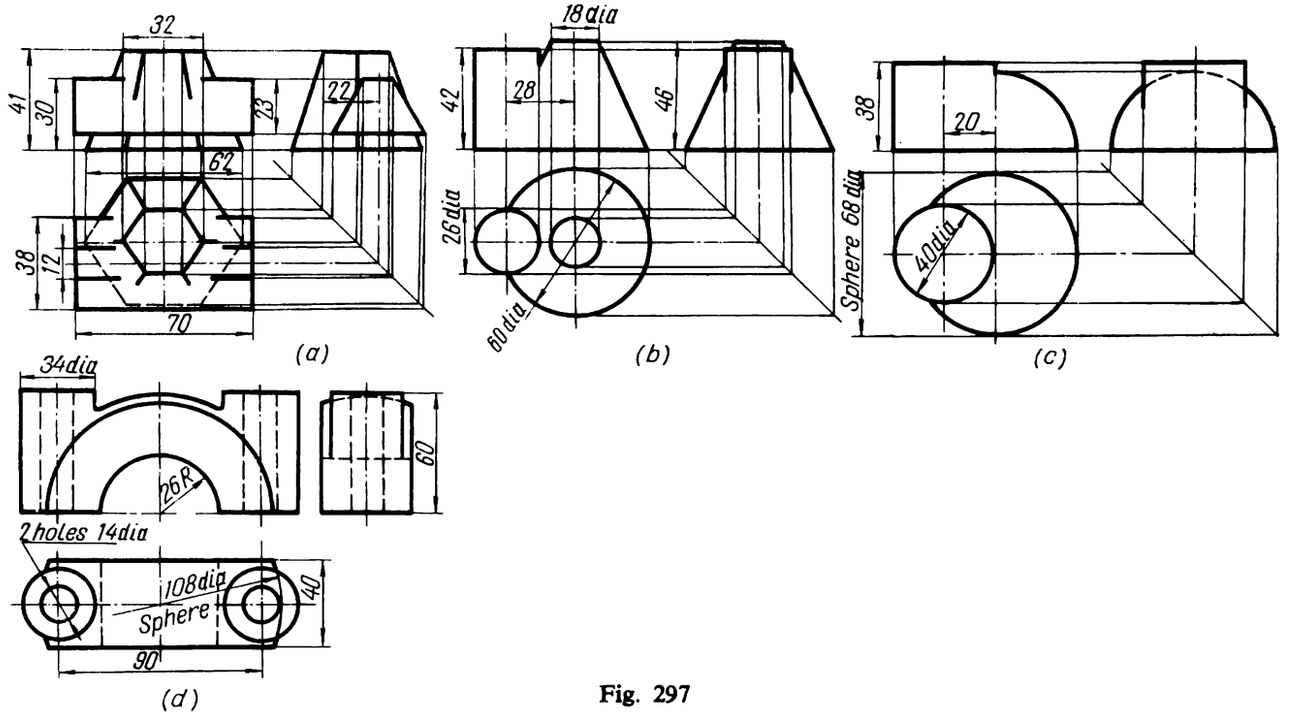


Fig. 297

4. Explain the method of finding the intersection line by spheres. When is it used?

5. When is one of the projections of the line of intersection of two cylinders represented by a straight line?

6. How is a development of two mutually intersecting cylinders made?

7. What is the shape of the lines of intersection of surfaces of revolution having a common geometrical axis?

8. How is the visibility of points on an intersection line determined?

Exercise 56

Find the intersection of the prism and pyramid shown in Fig. 297*a*.

Exercise 57

Find the intersection of the cylinder and cone shown in Fig. 297*b*.

Exercise 58

Find the intersection of the cylinder and sphere shown in Fig. 297*c*.

Exercise 59

Draw three projections of the machine part, Fig. 297*d*, and find the intersection lines of its surfaces.

CHAPTER 11

SECTIONAL VIEWS AND SECTIONS

The principles of projection thus far discussed state that the interior parts of a hollow object, which are hidden from view, can only be represented by dash lines or hidden lines as they are called. When these dash lines are too numerous the drawing is difficult to interpret. To overcome this predicament sectional views are used.

A *sectional view* is a view seen when a portion of the object nearest the observer is imagined to be removed by means of a cutting plane or planes, thus revealing the interior construction.

A sectional view is also used to show the exact shape of certain exterior parts which are curved or rounded so that the usual two- or three-view drawings do not reveal their true form.

To show the interior construction of an object, the main cutting plane is passed through an axis of symmetry parallel to one of the principal planes of projection. Other cutting planes, if necessary, are passed parallel or perpendicular to the main cutting plane.

A sectional view is represented by continuous lines as though the portion of the object nearest the observer is actually cut off by the cutting planes. It should be noted that the other views are not affected in any way.

To make the parts cut by the section plane stand out, cross-hatching, or section lining, is employed. This is done by drawing light continuous lines.

Depending on the position of the cutting plane relative to the horizontal plane of projection, sectional views, or sections, are divided into:

(a) *Vertical*, when the cutting plane is perpendicular to the horizontal plane of projection.

A vertical sectional view is called *frontal*, if the cutting plane *A* is parallel to the plane *V*

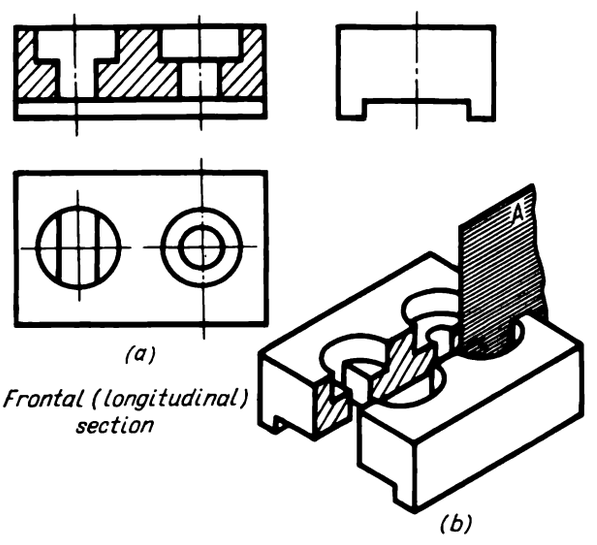


Fig. 298

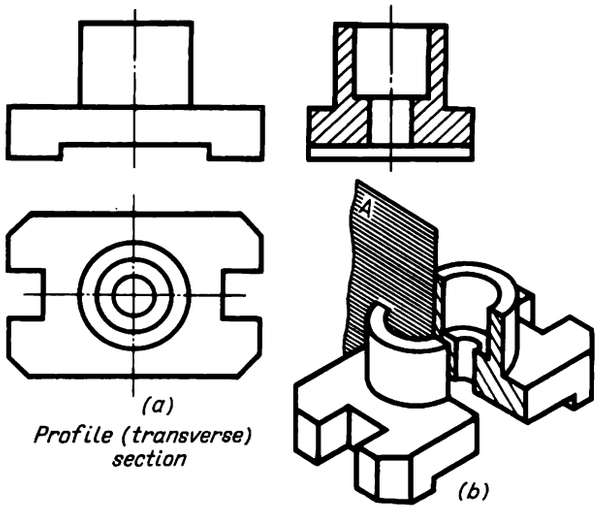


Fig. 299

(see Fig. 298*a* and *b*), and it is called *profile*, if the cutting plane is parallel to the plane *W* (Fig. 299*a* and *b*);

(b) *Horizontal*, when the cutting plane is parallel to the plane *H* (Fig. 300*a* and *b*).

Sectional views are called *longitudinal*, if the cutting plane passes along the length or height of an object, and *transverse*, if the cutting plane is perpendicular to the length or height of an object.

Here is an example. The vertical plane *A* in Fig. 298*b* passes completely through the part, cutting it along the plane of symmetry. One-half of the part, the one nearest the observer, is imagined to be removed, and the remaining half is projected on the plane *V*.

The following points should be strictly observed in making an orthographic drawing with one view in full section:

(a) Visible lines contained in the cutting plane and behind the section are shown.

(b) Invisible lines behind the section are omitted.

(c) Only the parts actually cut by the section plane are cross-hatched (with thin continuous lines drawn at an angle of 45° to the horizontal).

(d) The position of the cutting plane is not shown on the final drawing.

Fig. 299 displays a cross-sectional view of a part which is drawn in the manner described above.

A horizontal sectional view is shown in Fig. 300. In making the sectional view of this machine part (this time on the plane *H*) remove its upper half.

On three projections of a given machine part sections may be made by different cutting planes and are independent of each other. In other words, a section constructed on one view of an orthographic projection is not repeated on the other views.

When two perpendicular cutting planes are passed through an object on planes of symmetry, one-quarter of the object is imagined to be removed in drawing the sectional view. Fig. 301 shows the cube as it would appear in sectional

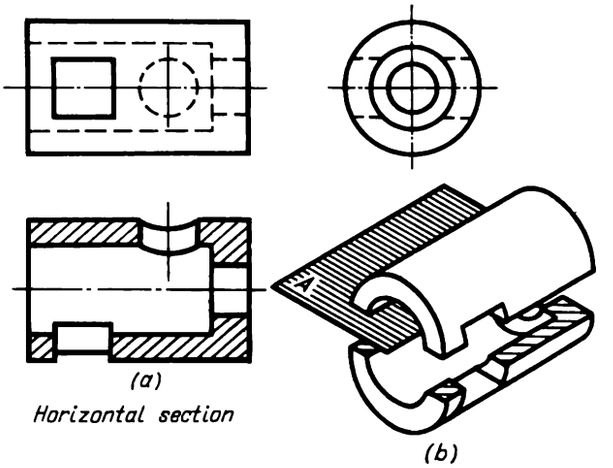


Fig. 300

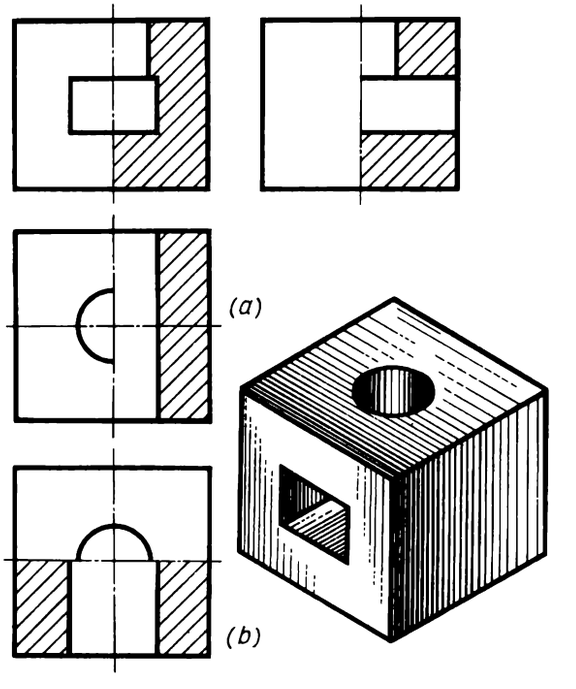


Fig. 301

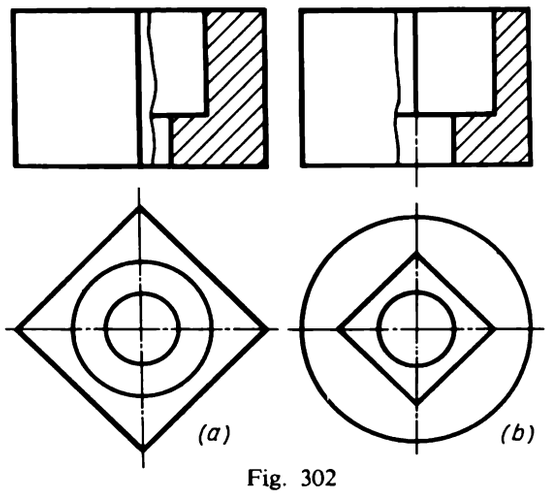


Fig. 302

views. It can be seen that only one-half of the view is shown in section and the other half is an external view. From this, the name *half-section* is derived for such a view. All the rules that have been given for drawing a full section also apply to half-sections.

In a half-section the interior part is separated from the exterior part by a centre line. It is standard practice to place the sectioned part to the right of an axis of symmetry or below it, as in Fig. 301*a* and *b*, respectively.

If a visible contour line of the outside surface is located on the axis of symmetry (for instance, an edge of a prism or pyramid), then the section is made somewhat less than one half, as in Fig. 302*a*. If a similar line of the inside surface lies on the axis of symmetry, then the section is made somewhat more than one half, as in Fig. 302*b*. In such cases the external view is separated from the sectional view by a thin continuous wavy line drawn freehand.

In making sectional views it is very important to clearly visualize the geometrical forms of the part (both inside and outside) and to correctly represent its interior shape in an orthographic drawing.

Shown in Fig. 303*b* is a model having mutual lines of intersection of inside and outside surfaces. Prior to constructing the orthographic projections of this model it is necessary to visualize the mutual intersections of surfaces and to decide what sectional views are to be made. In this case we have the following mutually intersecting surfaces: pyramid, prism, and cylinder. Fig. 303*a* presents three orthographic projections of the model with the profile view being sectioned somewhat less than one half, since one of the edges of the tetrahedral pyramid is projected on the axis of symmetry.

Two practical examples of machine parts whose drawings require sectioning are illustrated in Fig. 304. Shown in Fig. 304*a* is a multiple drilling machine head which is mainly bounded

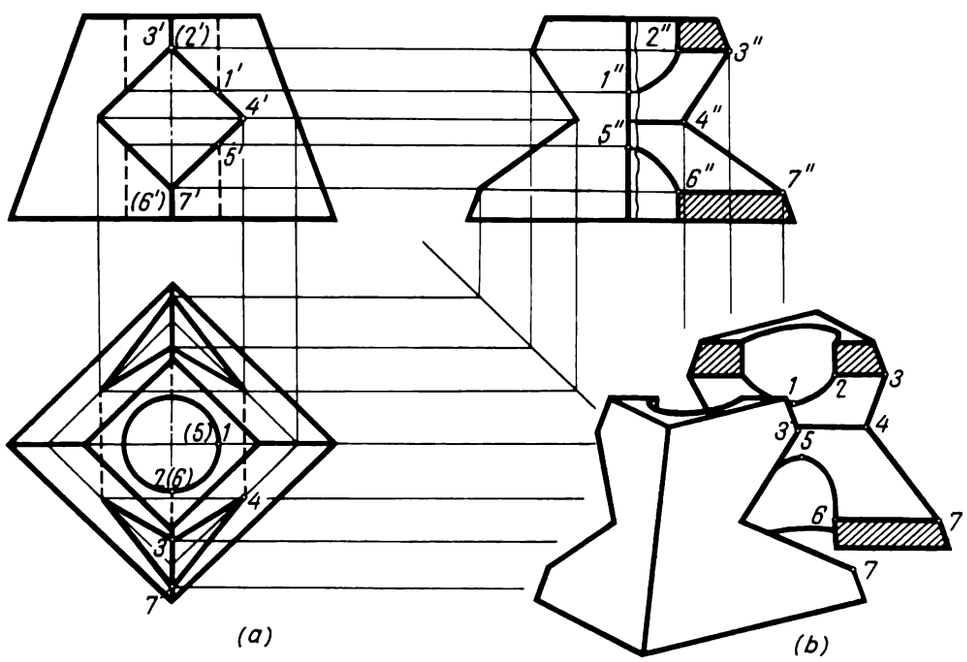


Fig. 303

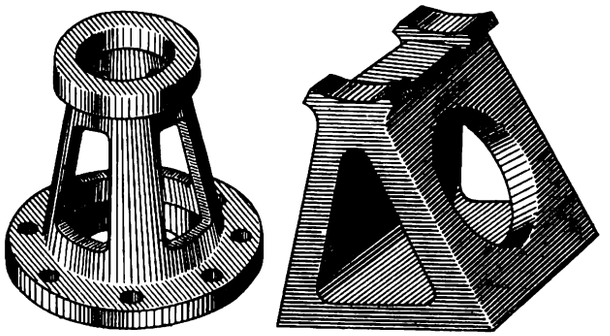


Fig. 304

by a conic surface with four openings. These openings are formed by four planes of which two are horizontal and two pass through the generatrices of the cone.

In constructing sectional views of such parts attention should be focussed on finding the lines of intersection of surfaces.

As distinct from a sectional view, a *revolved or removed section* of a given solid is a plane figure contained in the cutting plane.

Sections of one model or machine part represented on different projections should be cross-hatched in one and the same direction. Section lines should be evenly spaced on all projections, the spacing depending on the size of the figure to be cross-hatched. The standard practice is to space section lines at 2 to 10 mm; spaces of 2 to 4 mm are the most common.

Questions

1. State the definition and purpose of a sectional view.
2. What is the difference between a longitudinal section and a cross section?
3. How are sectional views of hollow models with holes of various shapes drawn?
4. When is it possible to combine one-half of an external view and one-half of a sectional view, and how are they arranged on orthographic projections?
5. What is the difference between a revolved or removed section and other sectional views?
6. How are sections cross-hatched?

Exercise 60

Construct three projections of the model shown in Fig. 305*a* and make vertical and horizontal sections.

Exercise 61

Draw the front view and plan shown in Fig. 305*b* in full size. Construct section *A-A*.

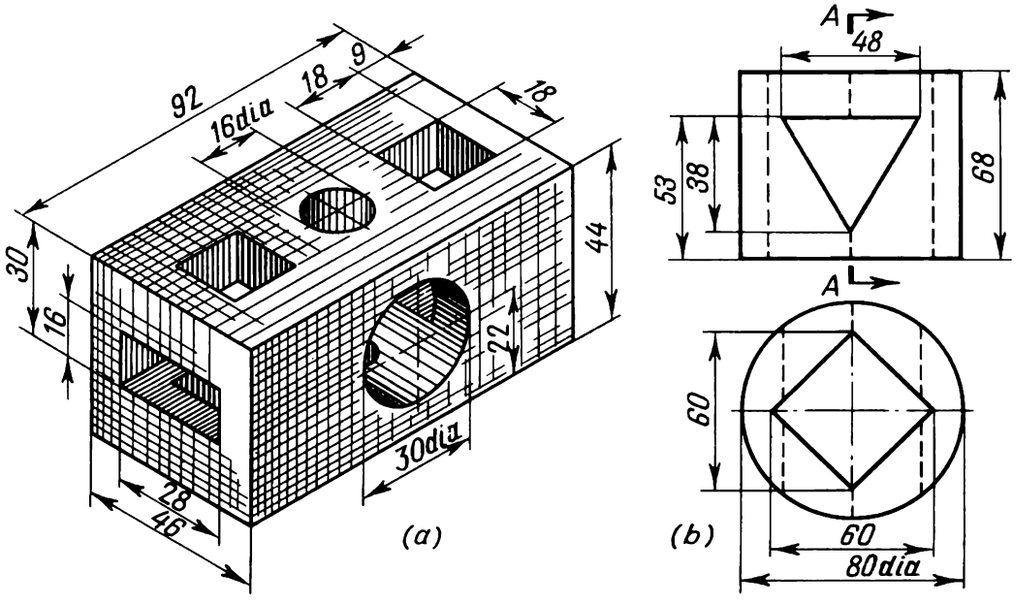


Fig. 305

IV
MACHINE DRAWING

CHAPTER 1

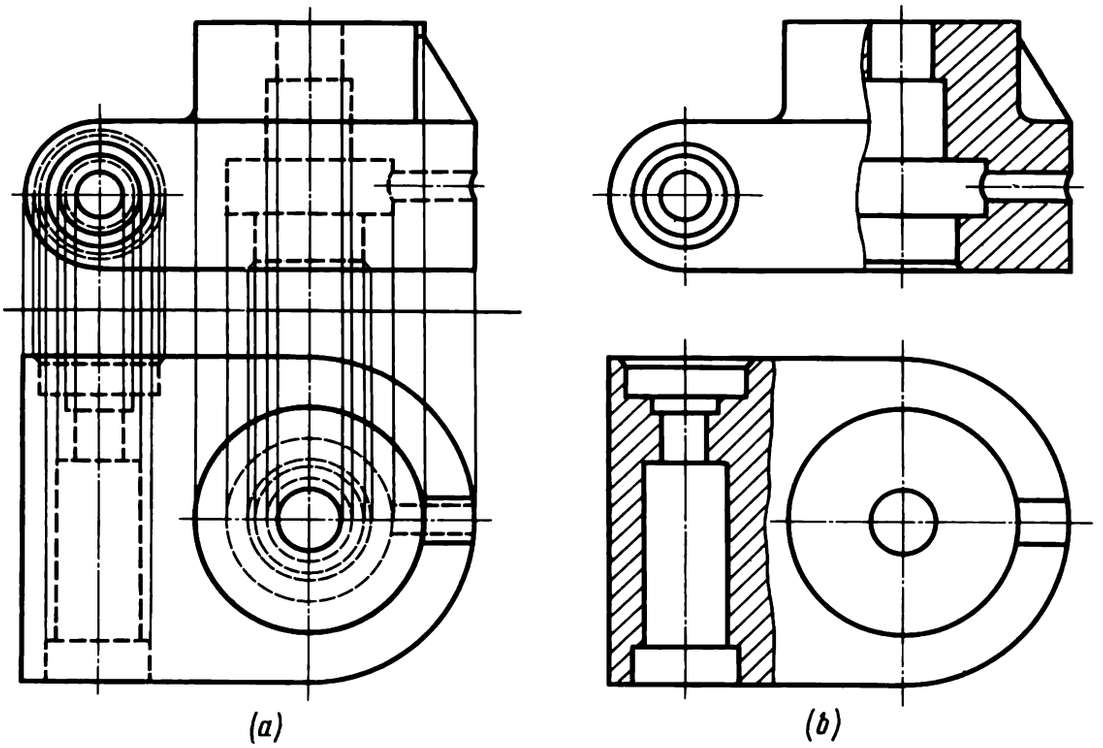
THE DRAWING AS A COMPONENT OF STANDARD ENGINEERING DRAWING PRACTICE

1. FEATURES OF MACHINE DRAWING

Machine drawing is based on the theoretical principles of descriptive geometry and projection drawing.

Unlike projection drawing, however, machine drawing is intended to provide supplementary information on the items being represented, and has a great many simplifications and conventions which are set forth in state standards on engineering drawing practice.

For instance, a machine drawing has no axes of projection and the minimum amount of short-dash lines are used to show hidden outlines and intersections. Shown in Fig. 306*a* is a simplified drawing of a machine part made according to the rules of projection drawing. It has many lines connecting the views and many hidden



(*a*) (*b*)

Fig. 306

lines. On a drawing of a more complex part, there would be many more such lines, making the drawing difficult, and sometimes impossible, to read. A machine drawing of the same part is illustrated in Fig. 306*b*. Here, simplified practice has been used, and the drawing is plain and clear, easy to read, and less time is required for making it.

Besides the representation of an object a machine drawing contains all the necessary data for its manufacture, inspection and assembly, for example, dimensions, the grade of the material, manufacturing specifications, surface roughness symbols, etc.

The aim of studying machine drawing is to learn, in detail, the rules for constructing the representation of objects on drawings. This also involves a study of the simplifications and conventions that have been adopted in engineering practice, the acquiring of skill in making sketches of machine parts, in reading and in making working drawings of such parts and assembly units, and in constructing diagrams. At the same time, the student should become acquainted with standards for drawing practice and with the standard parts that are more extensively applied in the engineering industries.

2. KINDS OF PRODUCTS

An item or set of items manufactured at a plant or works is called the product.

Depending upon their purpose, products are classified into those manufactured by the main production facilities and those made by auxiliary facilities.

The main items of production are those for whose manufacture the plant is intended and which are sold to the customers, for example, a power shovel produced by a construction machinery works or a precise dial indicator made by an instrument plant (Figs. 307 and 308).

Items of auxiliary production are the products made by the plant to satisfy its own needs, and consist mainly of tooling for manufacturing the main products. Such items may be a single-point cutting tool with a holder of special shape (Fig. 309), pressworking dies, fixtures and attachments for machine tools, or gauges made in the toolroom of the given plant. If the cutting tool or toolholder is to be supplied to other plants, then it is a main item of production.

The pertinent USSR standard establishes the following classification of the kinds of products: parts, assembly units, integrated systems, and sets.

A *part* is a product whose drawing *does not require a parts list.*

Assembly units, *integrated systems* and *sets* consist of two or more components and, consequently, *require a parts list* which enumerates the parts or component assemblies that make up the product. They may also require other documents containing information necessary for the manufacture of the product.

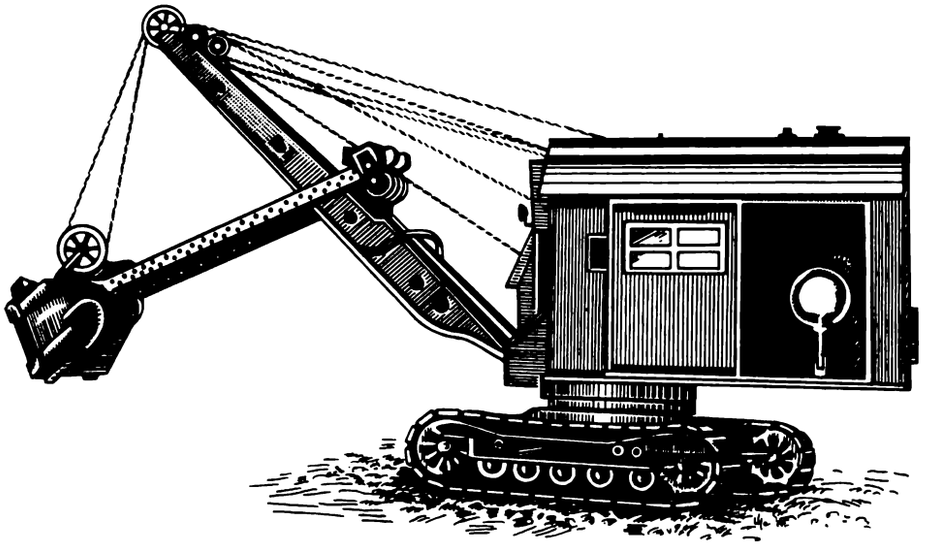


Fig. 307

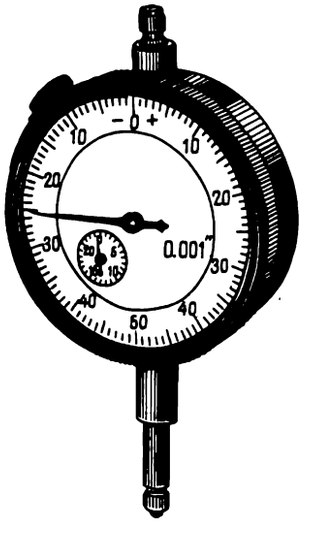


Fig. 308

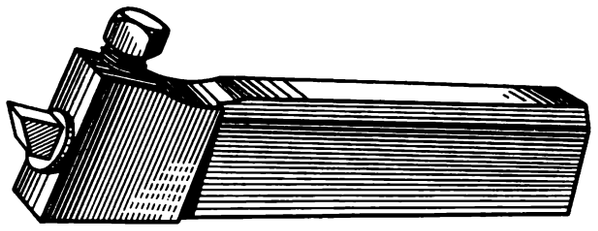


Fig. 309

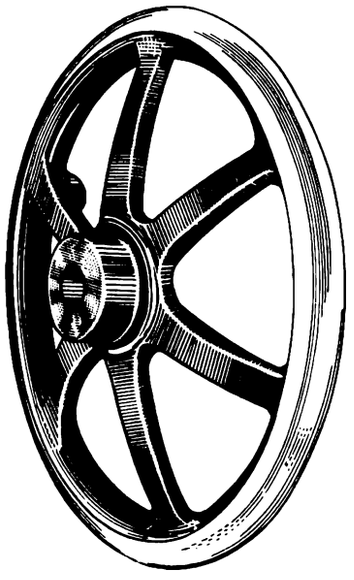


Fig. 310

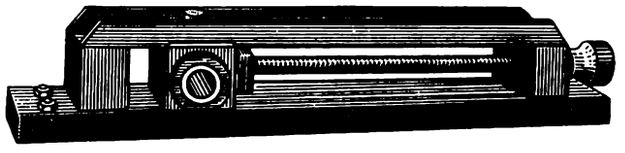


Fig. 311

A *part* can be defined as a product manufactured of a single grade of material and without the application of any kind of assembly operations. An example is the flywheel in Fig. 310.

An *assembly unit* is a product whose component parts are joined together at the manufacturing plant by assembly operations (such as bolting, riveting, welding, brazing, press-fitting, beading, adhesive bonding, industrial stitching, etc.). An example is the welded frame of a conveyer tensioning device illustrated in Fig. 311.

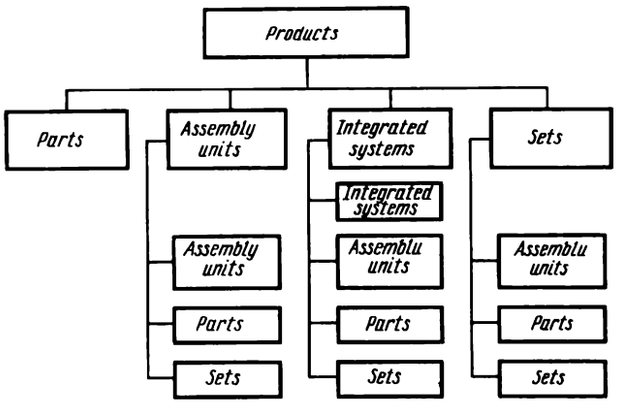


Fig. 312

An *integrated system* is two or more assembled products which are not joined together at the manufacturing plant by assembly operations, but are intended for interrelated operating functions. Examples are transfer lines of machine tools (also called transfer machines), automatic telephone exchanges, etc.

A *set* consists of two or more products, not joined together at the manufacturing plant by assembly operations, and having a common purpose of an auxiliary nature. They may comprise a set of tools and accessories for an automobile or a set of spare parts for a machine tool.

A classification chart of the kinds of products and their structure is given in Fig. 312.

3. TYPES OF DRAWINGS AND AUXILIARY DOCUMENTS

Designing and drafting documents may be either graphical (such as drawings and sketches) or textual (parts lists, manufacturing specifications, etc.) which, either separately or as a whole, determine the contents and construction of the product, and contain all the data necessary for its design, inspection, acceptance, maintenance, operation or manufacture.

The USSR drawing standard establishes a classification of drafting room documents for products in all branches of industry. This classification lists the following items:

1. A *detail drawing* is a representation of a given part and contains all the data necessary for its manufacture and inspection.

2. An *assembly drawing* (sometimes called a unit assembly drawing) is a representation of a given assembly unit and contains all the data

required for its assembly (or manufacture) and inspection. Hydraulic and pneumatic piping layout and electrical wiring layout drawings are also classified as assembly drawings.

3. A *general view drawing* is one that determines the design of a given product, shows the interaction of its chief components and explains its principle of operation.

4. An *outline assembly drawing* is a simplified representation (outline) of a given product and specifies the overall dimensions (full height, width and length), as well as installation and coupling dimensions.

5. An *erection drawing* is a simplified representation (outline) of a given product and contains all the data required for its installation (erection) at the site where it is to be employed. Also referred to as erection drawings are drawings of foundations which are specially designed for installing the product.

6. A *diagram* is a drawing in which the component parts of a given product and their interrelations are shown as conventional symbols or designations.

7. A *parts list* is a tabulated statement specifying the component parts of an assembly unit, integrated system or set.

8. A *tabular drawing* is one containing the pertinent data listed in a table. For example, a tabular drawing may be made for a group of parts which differ only in their dimensions, grades of material, coating, etc.

9. *Maintenance drawings* and other documents contain all the data required for doing repair jobs either at a specialized repair plant or at the maintenance department of the plant employing a given product.

Depending upon the *stage of design*, designing documentation, including drawings and other records, may be of either the *project* or *working* type.

Project documentation includes:

1. The design assignment.
2. The design proposal.
3. The preliminary design, which includes assembly drawings of the main units and a general view of the product.
4. The contract design, which includes finished unit assembly drawings and the finished general view, ready to be detailed.

Working documentation (drawings) includes:

1. Detail drawings of all the parts in the units.
2. Assembly drawings of the units and product.
3. Parts lists.
4. Outline assembly drawings.
5. Erection drawings.
6. Diagrams and other documents required in assembling and inspecting the product.

The working documentation is based on the design documentation.

Depending upon the way they are made and the purpose they serve, designing documents are classed as follows.

1. *Originals*, which are drawings and other documents made on any material (drawing paper or tracing cloth) and from which the first draft documents are made.
2. *First drafts*, which are drawings and other documents carrying signatures of the persons participating in the designing and drafting work. These documents may be made on any material from which copies can be reprinted.
3. *Duplicates* are identical copies of the originals, made on any material that allows copies to be reprinted from them.
4. *Copies* or *prints* are drawings or other documents reproduced from and identical with the originals (or duplicates) and intended for use in working out designing drawings and documents, and for the manufacture, operation and maintenance of the product.

Drawings and documents to be used a *single time* at a shop may be made by freehand sketching. According to the way they are made and their purpose, such sketches are similar to the documents mentioned above.

The *basic drawing documents* are the *detail drawings* for parts, and the *parts lists* for assembly units, integrated systems and sets.

All designing documents in the USSR, except the basic ones, are identified by a code. For instance, *AD* stands for an assembly drawing, *OA* for an outline assembly drawing, *MS* for manufacturing specifications, etc.

Depending upon the stage of design, designing documents and drawings have the index *C* for the contract design, *P* for the working drawings from which the prototype or initial lot is manufactured, and the index *R* for documents used in regular production.

All drawings made for training purposes may have the index *T*.

The detail drawings for main and auxiliary production are to be made according to stand-

ards of engineering drawing practice as to features that facilitate their filing and revision.

If necessary, drawings for tooling and other auxiliaries may be simplified to some extent.

4. THE TITLE BLOCK ON MACHINE DRAWINGS

A considerably simplified form of drawing title block is illustrated in Figs. 18 and 20, in which the information given and the method of filling in the title block and its dimensions are applicable for school purposes. A more detailed title block according with the standard form No. 1 is to be used for machine drawings. Its form and size are stipulated by the pertinent USSR standard. An example of a title block is given in Fig. 313, in which the spaces are filled in for a training drawing of a part in machine drawing practice.

Space *1* is for the title, or the name of the part represented (in the singular and without carrying any syllables over to the next line). No period follows the name. If the name consists of more than a single word, the words should be in regular order with any descriptive adjectives preceding the noun, for example, "Helical Gear". Space *2* is for the code designation of the document (drawing or diagram) as stipulated by the pertinent drawing practice standard.

Since the use of such numbers on training drawings may lead to some difficulties, a simplified designation consisting of letters and figures can be recommended. An example is shown in Fig. 313, where the letters *MD* stand for machine drawing, the figure *08* for the number of the assignment, and figure *14* for the number of the drawing. The designation for training assembly drawings may be somewhat different.

Indicated in space *3* is the material of which the part is to be made (this space is to be filled in only in detail drawings). The index is put into space *4*. In our case, we can use the letter *T*.

According to the USSR standard, the index in space *4* should indicate the stage of design. Space *5* shows the mass or weight of the part (the space is filled in only for detail drawings).

The other spaces in the title block are intended for:

space *6* — scale of representation;

space *9* — name of the school and class number;

space *10* — type of work done by the person that signs the drawing, for example: designed, consultant, drawn, checked, etc.;

space *11* — lettered names of the persons signing the drawing;

space *12* — signatures of the persons whose names are given in space *11;*

space *13* — date the drawing is signed.

The rest of the spaces are not filled in on training drawings.

According to the standard drawing practice, an additional space is provided in the upper left-hand corner of the drawing for repeating the drawing designation upside down (with respect to that in space *2*) for convenience in case the drawing is reversed in the drawer where it is kept. The size and arrangement of this additional box is shown in Fig. 314.

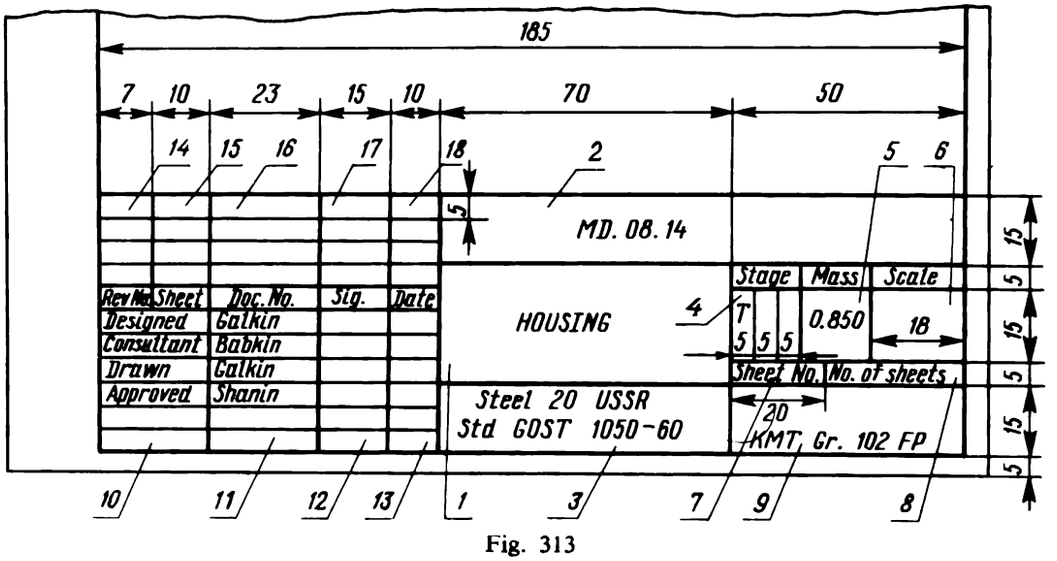


Fig. 313

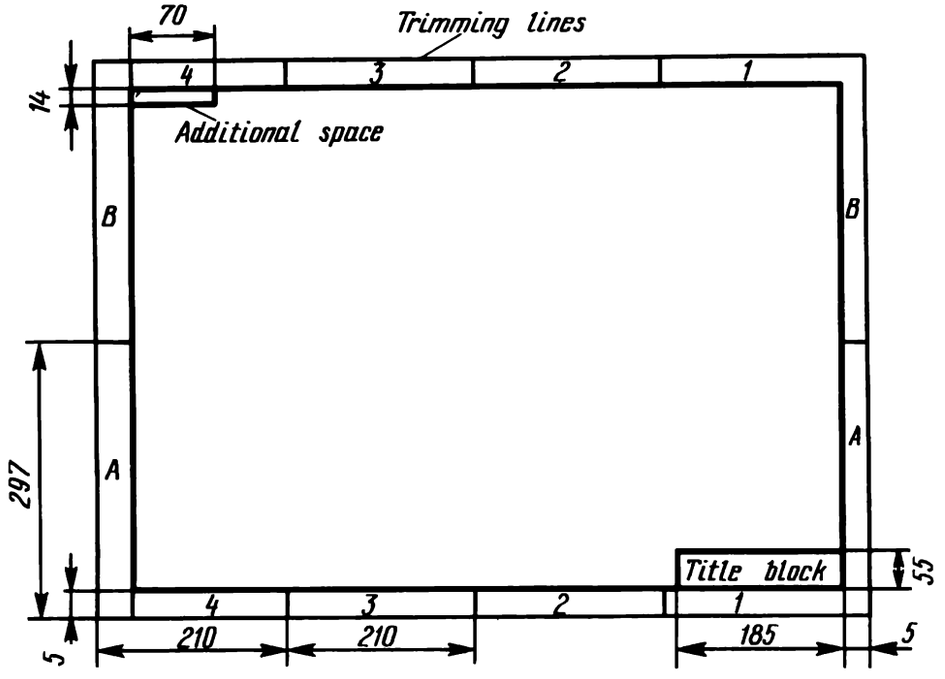


Fig. 314

Also shown in Fig. 314 are marks which divide the area of the drawing into zones in cases where it is necessary to provide a way to readily find some element of the representation on the drawing. These marks are made at distances equal to one of the sides of a Size 11 sheet. The zones the marks divide the drawing into are designated horizontally by Arabic numerals, from right to left; and vertically by capital letters, from the bottom upwards. Thus the zones are indicated by a letter and a number, such as *A2*, *B1*, etc.

CHAPTER 2

VIEWS, SECTIONAL VIEWS AND SECTIONS IN MACHINE DRAWINGS

Parts are made and assembled according to drawings.

A drawing must contain exhaustive information concerning the shape of the object, its design, dimensions, material, surface finish, and many other facts.

When working on structures and machines, designers often deal with complicated parts and elements for the representation of which the three projections (on the planes H, V and W) considered in Part Three, Chapter 2, are insufficient. In such cases, the six faces of a box shown in Fig. 315*a* are taken as the principal planes of projection, the three additional planes being denoted as H_1, V_1 and W_1.

An object is located inside the box and projected orthographically on each face, assuming that the object is located between the viewer and the corresponding plane of projection. Thus we can draw six views which, when all the planes of projection are brought into alignment, will conform with the USSR Standard* (see Fig. 315*b*).

* The plane V_1 may also be placed next to the plane W_1.

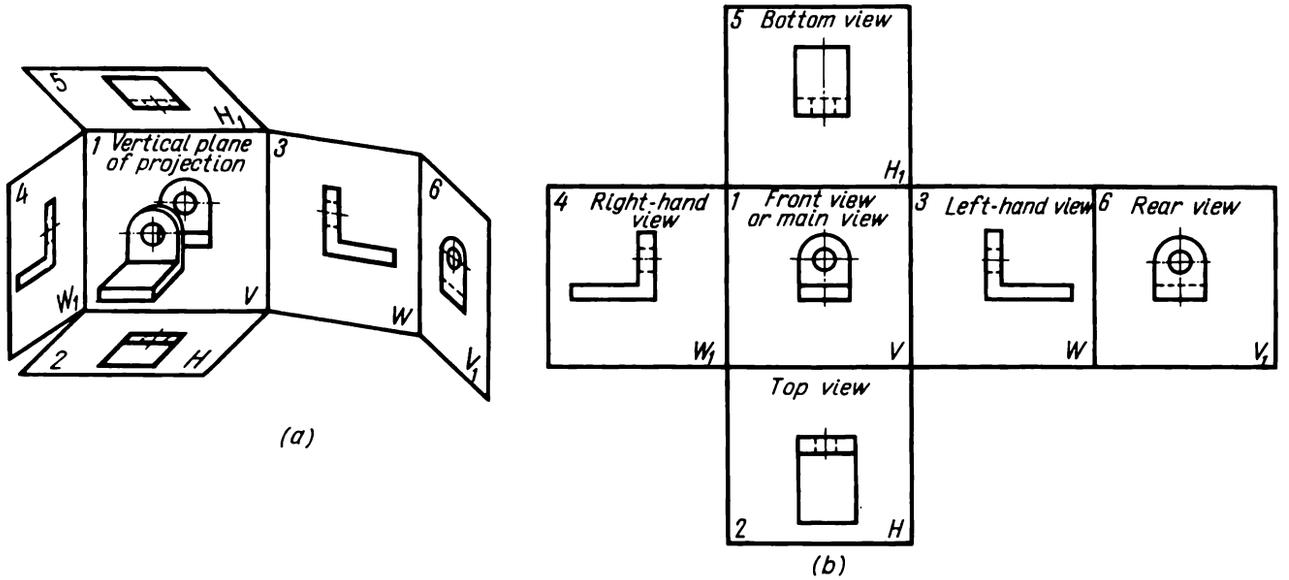


Fig. 315

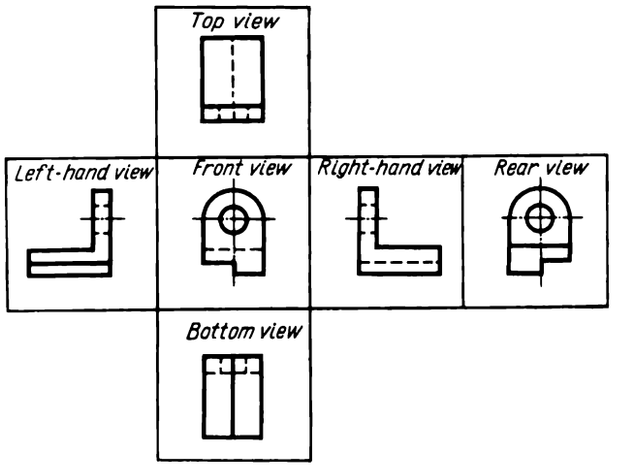


Fig. 316

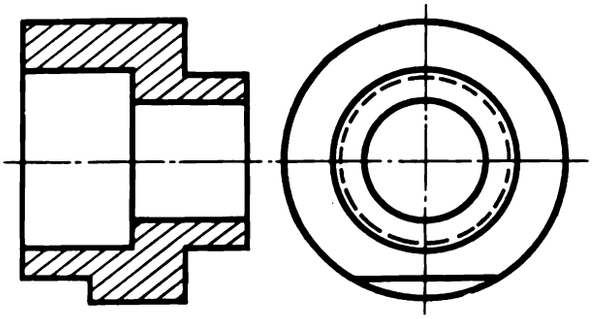


Fig. 317

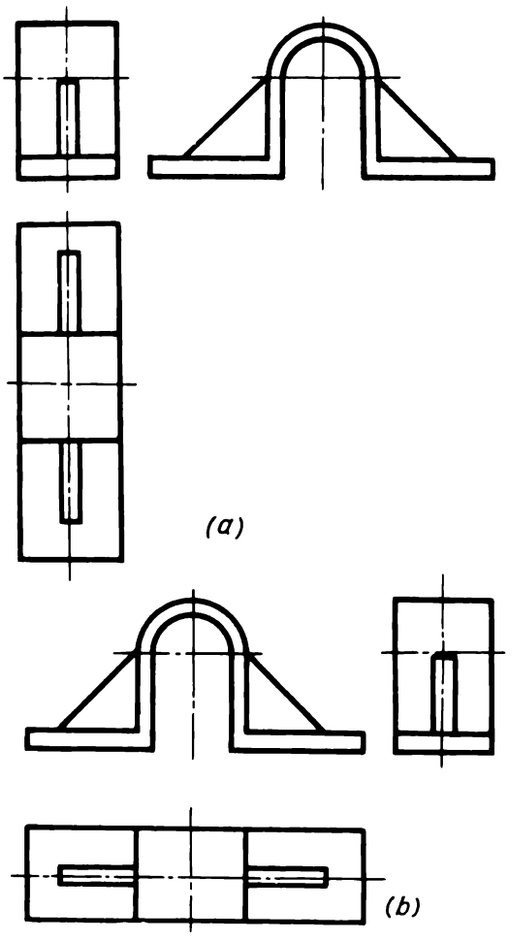


Fig. 318

1. VIEWS

The projection of the visible portion of the surface of an object facing the viewer is called a *view*. The six views obtained on the above mentioned planes of projection are called: 1 — *front or main view* (also *vertical projection* or *front elevation*); 2 — *top view (horizontal projection* or *plan)*; 3 — *left-hand view*; 4 — *right-hand view*; 5 — *bottom view*, and 6 — *rear view*.

The names of the views are not given in drawings when they are arranged as stipulated by the above mentioned standard. All these views should always be in horizontal or vertical alignment with the front or top views. Projectibility from one view to another is very important and must be maintained rigidly in training drawings.

The standard arrangement of views practised in the USA, Great Britain, and the Netherlands differs from that used in the USSR (see Fig. 316).

When drawing the main view of a machine part, the latter should be placed with respect to the plane *V* so that it occupies (if possible) the working position and reveals its shape and dimensions to the best advantage. Such parts as axles, shafts, bushes, sleeves, tubes, etc., are usually represented on the main view with the axis in the horizontal position, and not necessarily in the working position (Fig. 317). The space of a standard paper sheet should be utilized rationally, as in Fig. 318*b*, Fig. 318*a* illustrating poor practice.

The number of views in an orthographic drawing must be minimum but sufficient to form a complete conception of the shape and dimensions of the object.

To make the most efficient use of the drawing space and to save time while making shop drawings the views are arranged in a specific way. Plans, left-hand, right-hand, bottom and rear views may be located without orthographic connection to the main view; some views may be incomplete in which case they are bounded by a break line or an axis of symmetry. In Fig. 319, for example, the view facing arrow *B*, or the bottom view, is placed not above the main view, as in the usual standard arrangement, but

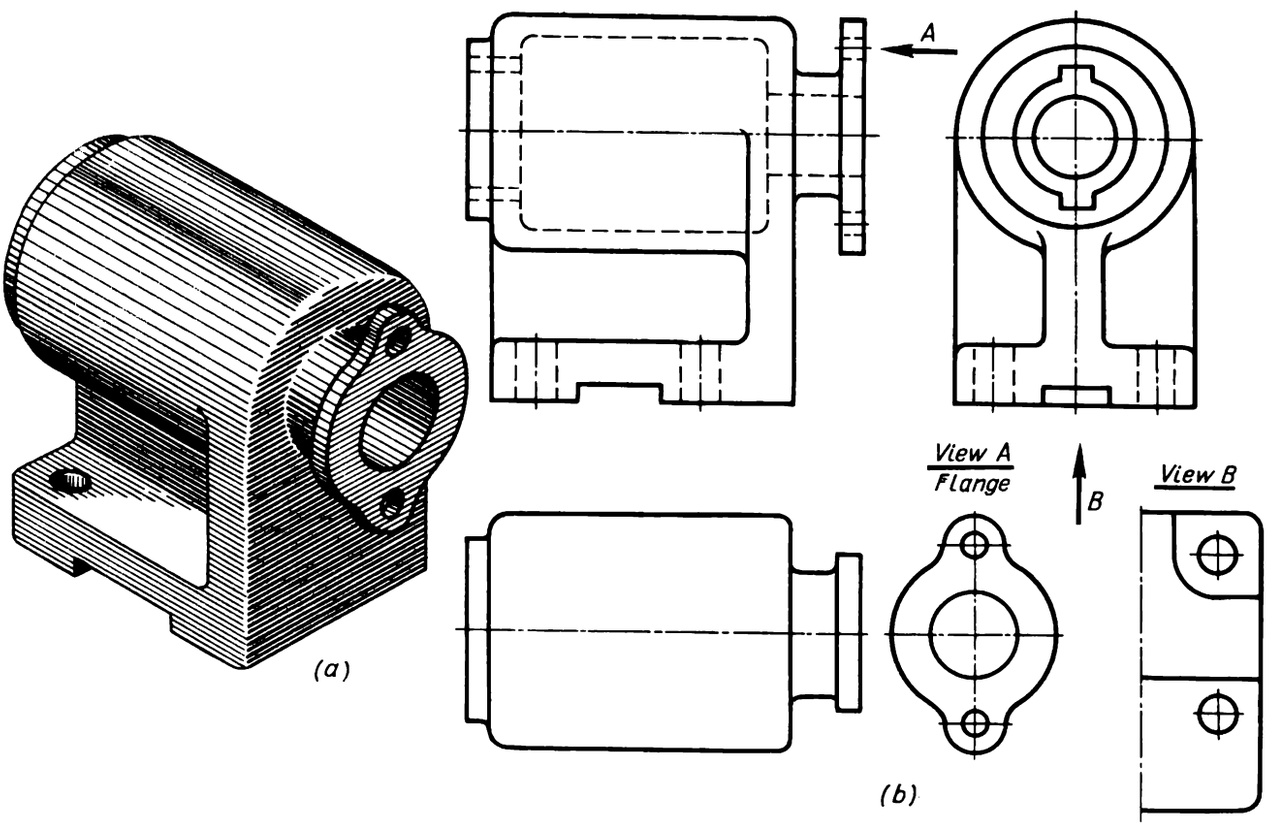


Fig. 319

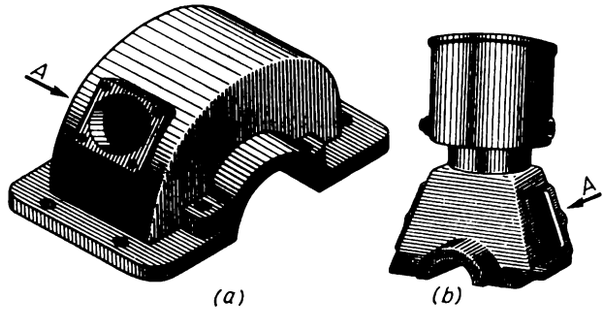


Fig. 320

below it and shifted to the right. In addition, it is not aligned with the main view and is incomplete. The other view of the part — view facing arrow *A*, or the right-hand view — is out of alignment with the main view and is also incomplete.

According to the USSR Standard top, left-hand, right-hand, bottom, and rear views must be designated as *View A*, *View B*, etc., these inscriptions being underlined as in Fig. 319. The direction of viewing is indicated by an arrow designated by the corresponding letter. If such an indication cannot be made, then the view must be named accordingly (say, *Bottom view*).

Besides the above considered views, mechanical drawings sometimes use views with replaced planes of projection (auxiliary views facing arrows). They are resorted to when none of the six principal planes of projection gives the true shape and dimensions of a certain machine part or its element. Then auxiliary views are employed, which are on planes parallel to none of the principal planes of projection.

In making drawings of the machine parts shown in Fig. 320 the following auxiliary views are required. On the drawing of a reducing gear cover (Fig. 320*a*) a view facing arrow *A* must be given to show the pad for the hatch. A similar view is essential in making an orthographic drawing of the engine head shown in Fig. 320*b*.

Distorted portions of a part are usually not shown on such views.

Examples of arranging auxiliary views are given in Figs. 321 and 322.

Fig. 321*b* shows a bracket. To avoid constructing several ellipses on the horizontal projection (Fig. 321*a*), the orthographic drawing should be represented as in Fig. 321*c* with the upper portion projected on an auxiliary plane of projection. Such projections should be constructed using the method of replacing projection planes set forth in Part Three, Chapter 5.

Auxiliary views (say, the view facing arrow *A*) must be accompanied by the corresponding inscriptions, for instance, *View A*, and the appropriate projection of the part must be supplied with an arrow indicating the direction of viewing (see Fig. 321*c*).

According to the USSR Standard the word *VIEW* may be lettered in capitals.

To conveniently arrange all the necessary views on a standard sheet an auxiliary view may be turned through any desired angle. In this case the word *turned* should be added, which is placed below the inscription *View A*, as in Fig. 322.

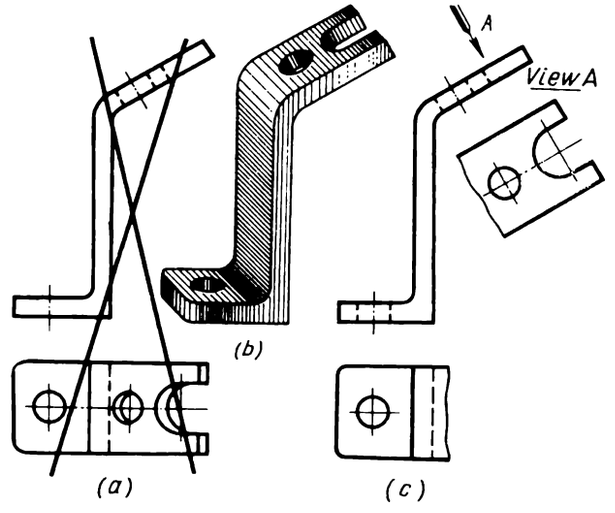


Fig. 321

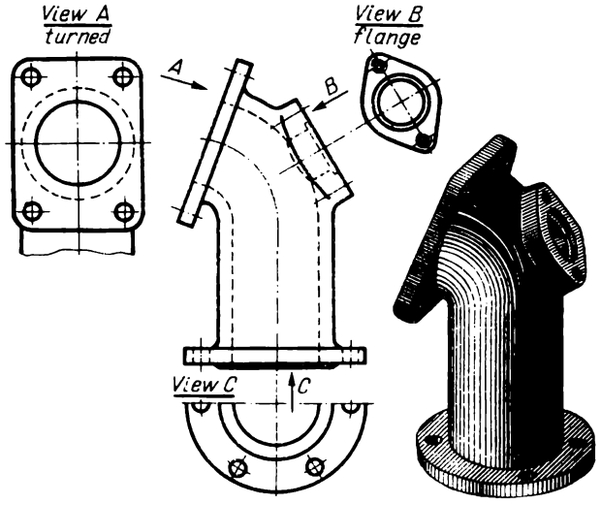


Fig. 322

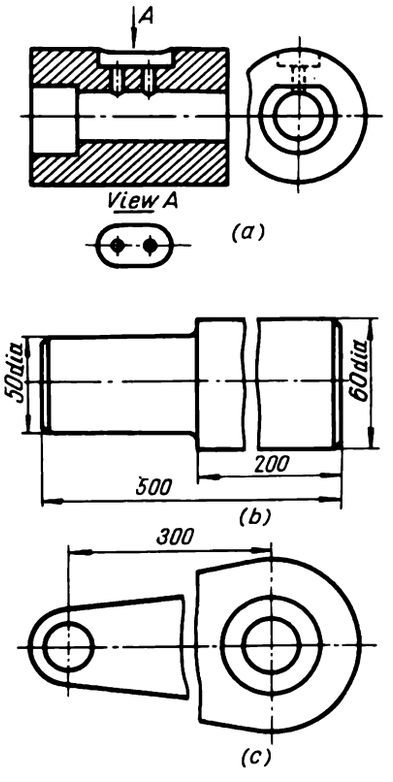


Fig. 323

Sometimes it is necessary to show a certain place on the surface of a machine part whose orthographic views give no clear idea of this area. In such instances the drawing is supplied with an additional view of this area which is called a *local view*. The latter may be limited by a break line as in Fig. 322 *(View A)* or be represented as in Fig. 322 *(View B)*. A local view, like an auxiliary one, is accompanied by an inscription indicating the name of the part element depicted; for example, *View B flange* (see Fig. 322).

To simplify the process of drawing, *limited* (or *incomplete*) *views* are used (Fig. 323*a*). In this figure the horizontal projection of the bush is incomplete, showing only those elements which are not given on the other two views.

Breaks may serve another purpose, namely, to shorten certain views of long parts having similar cross sections throughout the length as in Fig. 323*b* and *c*. If a view has a break, the dimension line must be drawn without breaks, the dimension figure indicating the true length of the part (Fig. 323*b*). Fig. 323*c* illustrates a break of a part with cross sections varying in height.

2. SIMPLE SECTIONAL VIEWS

As was already mentioned, a sectional view is a view seen when a portion of the object nearest the observer is imagined to be removed by means of a cutting plane or planes, thus revealing the interior construction. The other views are not affected in any way and always represent the entire object.

Depending on the number of cutting planes, sectional views are classified as *simple* (with one cutting plane) and *complex* (with two or more cutting planes).

Shown in a sectional view are usually the section and everything situated behind it. According to the USSR Standard some elements behind the cutting plane may be omitted.

In addition to what was stated in Part Three, the student should know that, depending on the position of the cutting plane relative to the horizontal plane of projection, sectional views may be *horizontal* (when the cutting plane is parallel to the horizontal plane of projection), *vertical* (when the cutting plane is perpendicular to the horizontal plane of projection), and *oblique* (when the cutting plane forms an acute angle with the horizontal plane of projection).

If the cutting plane is parallel to the vertical plane, then the vertical section is called a *frontal section*, and if the cutting plane is parallel to the profile plane of projection, the section is called a *profile section*.

Shown in Fig. 324 is a pedestal cut on the axis of symmetry by a frontal plane P (at *a*), and a frontal sectional view on the plane V (at *b*). The section is cross-hatched with thin lines slanted at an angle of 45°.

The bearing cap shown in Fig. 325 is cut by a profile plane A, its left half is removed, and

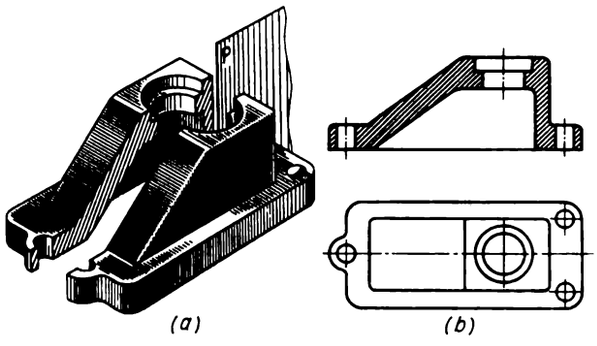


Fig. 324

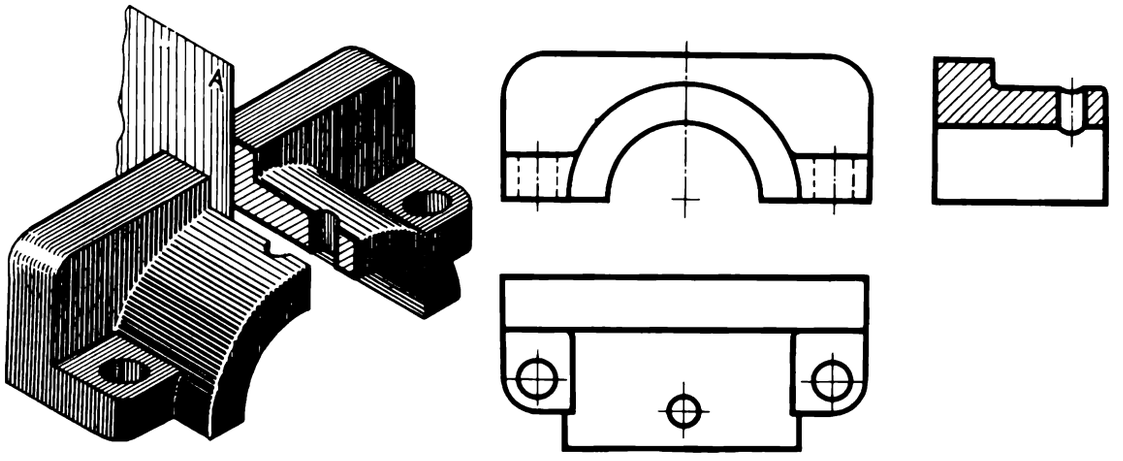


Fig. 325

the remaining half is projected on the plane *W* thus producing a profile sectional view.

An example of a horizontal sectional view is seen in Fig. 326 where a bearing is cut by a horizontal plane.

The sections obtained in the above three examples are non-symmetrical figures. If the projection is a symmetrical figure, then a combination of an external view and a sectional view is also permitted, the halves being usually separated by a fine dot-and-dash line (the line of symmetry) or by a wavy break line. This is illustrated in Fig. 327 where a casing is cut by different section planes.

In the pictorial representation at the extreme left two perpendicular cutting planes are passed part way through the casing on planes of symmetry, and one quarter of it is imagined to be removed. The drawing shows the casing as it would appear in a sectional view: only one-half of the front view will show in section and the other half will be an external view.

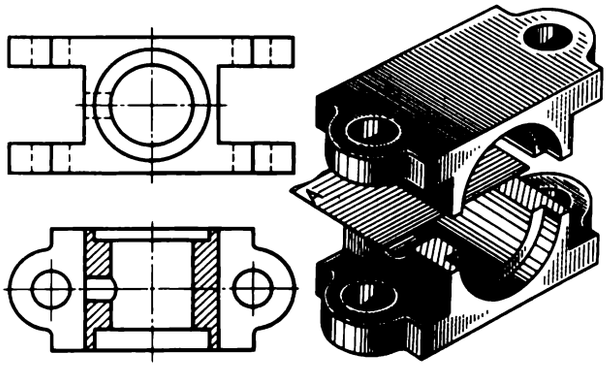


Fig. 326

Constructed on the right is a half-section of the same casing cut by a profile plane.

The lower part of Fig. 327 exhibits two half-sectional views of the same casing cut by a horizontal plane.

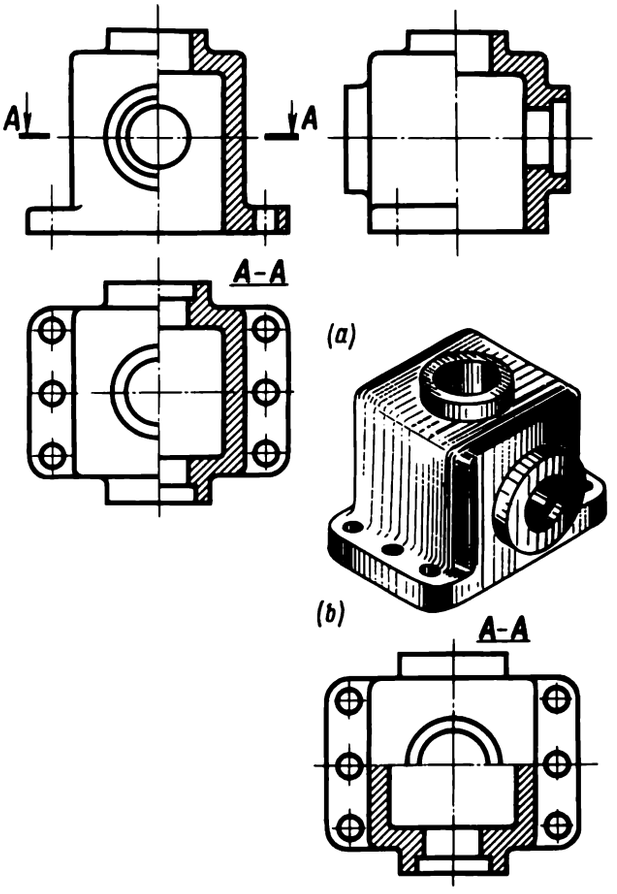


Fig. 327

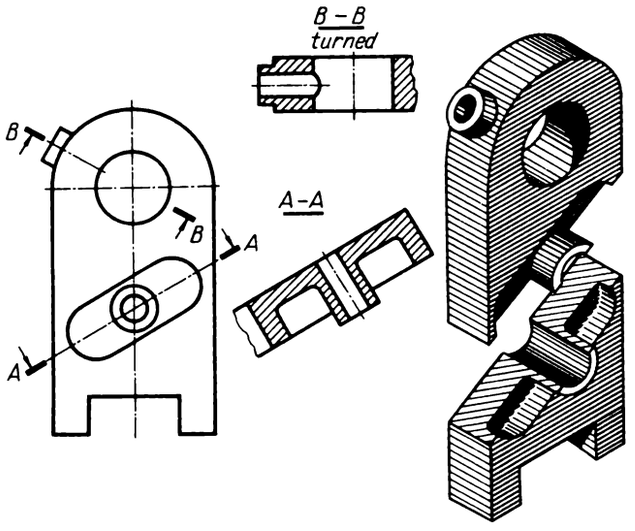


Fig. 328

Above is one-half of an external view separated from a half-sectional view by the vertical axis of symmetry.

Below is a combination of an external view and a sectional view separated by the horizontal axis of symmetry.

In both cases the hidden lines are omitted.

To have a complete orthographic representation of the cover shown in Fig. 328 it is not sufficient to use cutting planes parallel to the principal planes of projection. To reveal the design of important elements two cutting planes perpendicular to the plane *V* but inclined to the plane *H* are introduced, and two sectional views are thus obtained: *A-A* and *B-B*, the latter being turned.

When a cutting plane is passed on an axis of symmetry, it is not necessary to indicate the location of the plane. If, however, a cutting plane is passed otherwise, its location must be shown in the view where it appears edgewise. The symbol used for the cutting plane is a heavy open line, as shown in Fig. 328, consisting of two dashes supplied with arrows indicating the direction of viewing. The dashes must not intersect the view. The arrows should be somewhat thinner than the dashes.

Shown in Fig. 329 are several versions of sectional views made according to the standard.

3. BROKEN-OUT SECTIONS

In certain instances an individual interior detail has to be singled out. Then the draftsman should break out a small portion of the outer part covering just the particular area. The break is outlined with a thin irregular wavy freehand line (see Fig. 330). This line must not coincide with any contour or centre lines of the view.

An example of a broken-out section is seen in Fig. 330.

If an element of a machine part requires some explanations as to its shape and dimensions because of the small size of its representation, then it is usually shown in an additional view drawn to a larger scale. According to the USSR Standard such a view is called a *removed element* (see Fig. 331). The appropriate place in the drawing (whether on an external view, sectional view, or other section) is indicated by a circle or oval drawn in a thin continuous line accompanied by a Roman figure put above the leader, as in Fig.

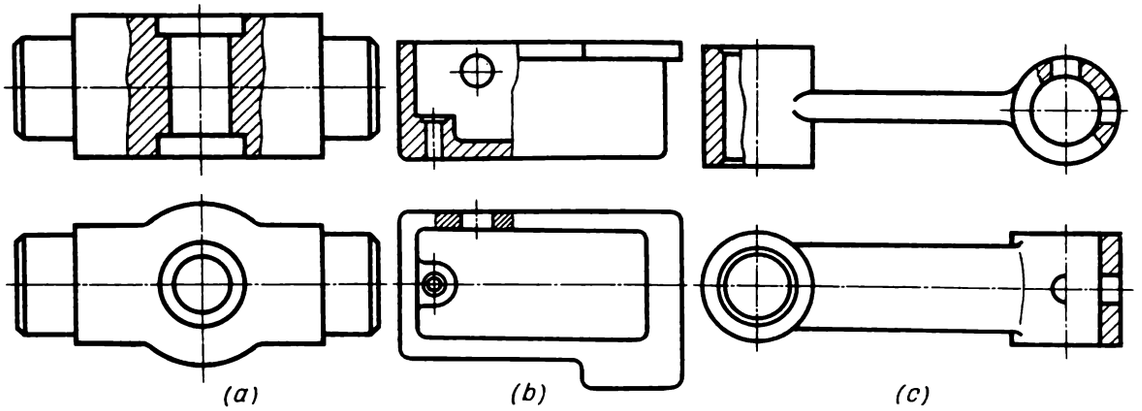


Fig. 329

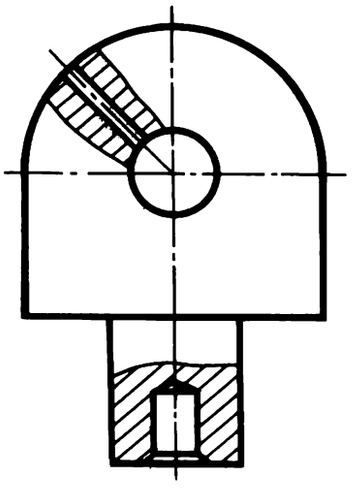


Fig. 330

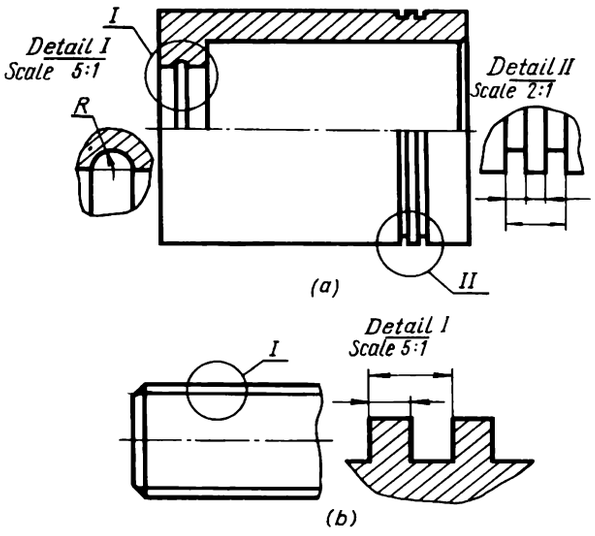


Fig. 331

331. A removed element, or detail, is usually supplied with an inscription comprising the same figure and the scale. One view may have several removed elements (see Fig. 331*a*).

The standard practice is to locate a removed element as close as possible to the corresponding place on the view.

A removed element may show some details which are not seen on the corresponding view, as in Fig. 331*b;* besides, it may differ from the latter in form: for instance, the element may be a sectional view, though it is removed from an external view (same figure).

4. COMPLEX SECTIONAL VIEWS

(a) Offset Sections with Parallel Cutting Planes

Section cutting planes are almost always passed through axes of symmetry of the object. If several such axes of symmetry occur, the cutting plane may be offset, as in Fig. 332*a* (strictly speaking, the part is cut by three frontal planes A, A_1 and A_2), to include two or more axes of symmetry. No particular difficulty is experienced in reading a drawing when this is done; yet it

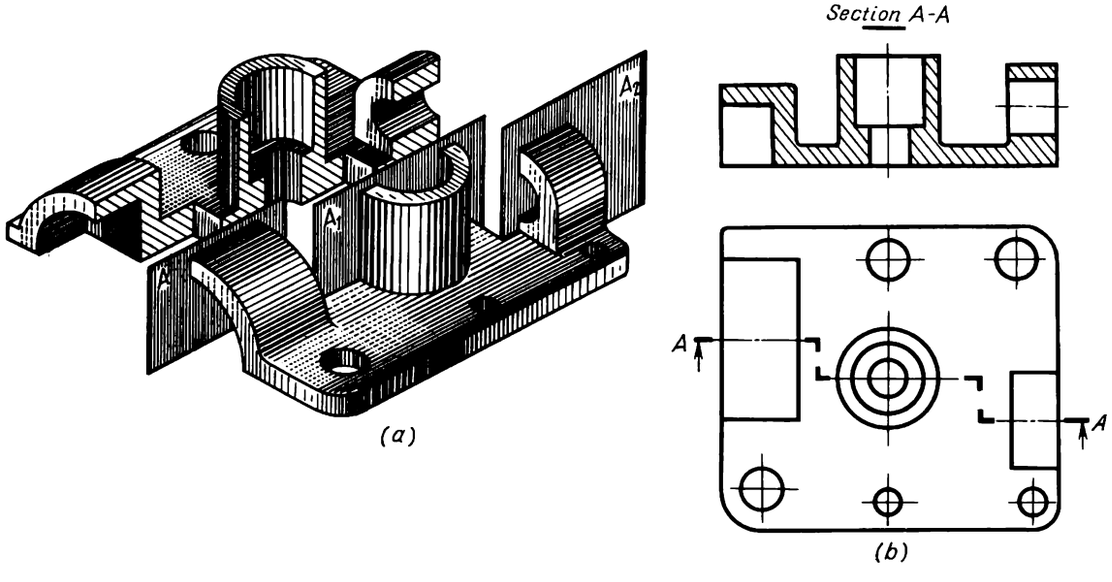


Fig. 332

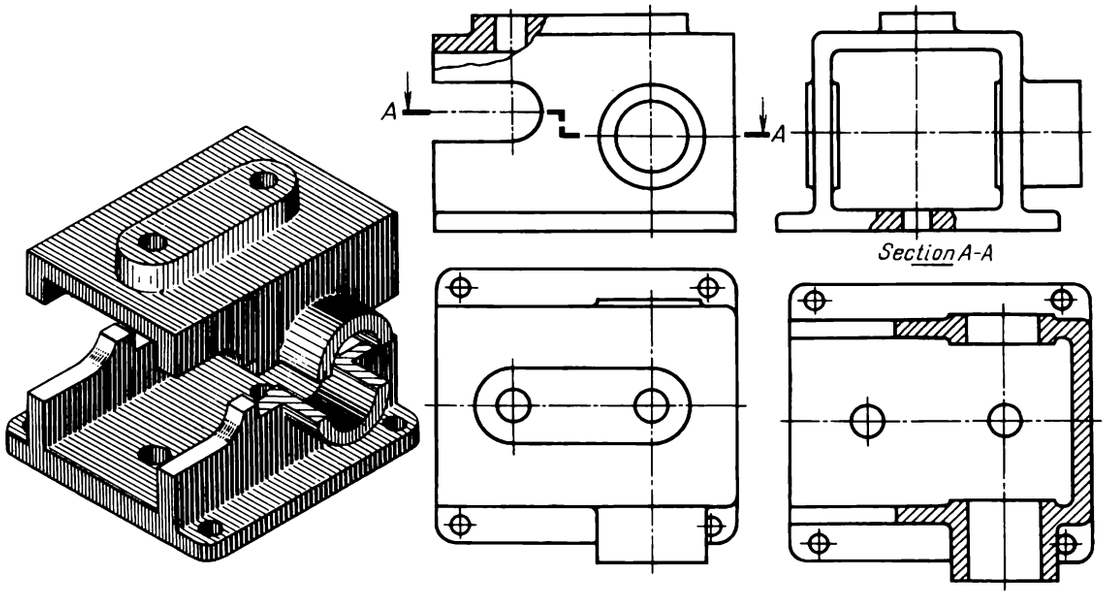


Fig. 333

is always best to show the location of the offset cutting planes by the characteristic dash line, and the direction in which the view is taken by arrows on the end of the line. These arrows should always point to the sectional view. No indication of the offsets in the cutting plane is shown on the sectional view, i.e., the three cutting planes are conventionally aligned (see Fig. 332*b*).

Offset section can also be obtained as a result of cutting an object with several horizontal planes (section *A-A* in Fig. 333). This section is shown on a separate view, as otherwise some elements of the part would not be seen on the top view.

(b) Offset Sections with Intersecting Cutting Planes

In sectioning certain objects, more information can be given if the section plane is turned through an angle, as shown in Fig. 334. The two segments of the cutting plane (the upper segment is a vertical projecting plane, the lower a profile plane) are imagined to be revolved until they are parallel to the principal plane of projection. This shows all cut portions of the object in true size in the sectional view (Fig. 334*b*). No indication of the bends in the cutting plane is shown in the sectional view. The position of the cutting plane is shown on the drawing by the usual symbol (by marking only the points

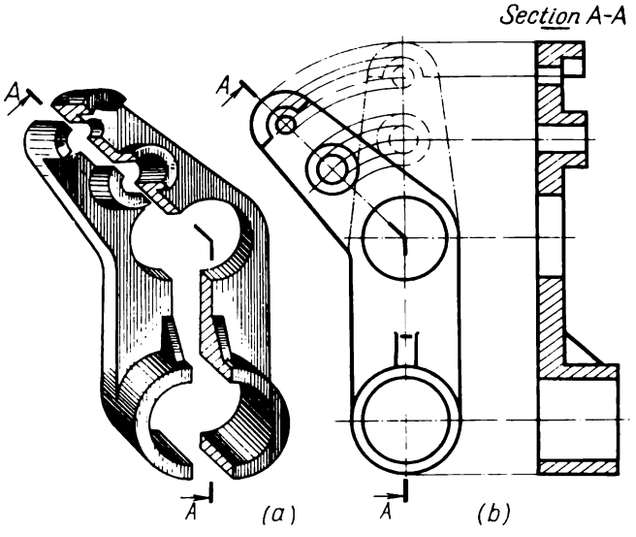


Fig. 334

of turning or bending) to indicate the edgewise view of the cutting plane. Arrows pointing to the sectional view show the direction in which the section has been taken.

5. REVOLVED SECTIONS

In many cases the cross section of some part of a structure or machine is necessary for the purpose of shape or size description. Frequently the easiest way to obtain this without drawing

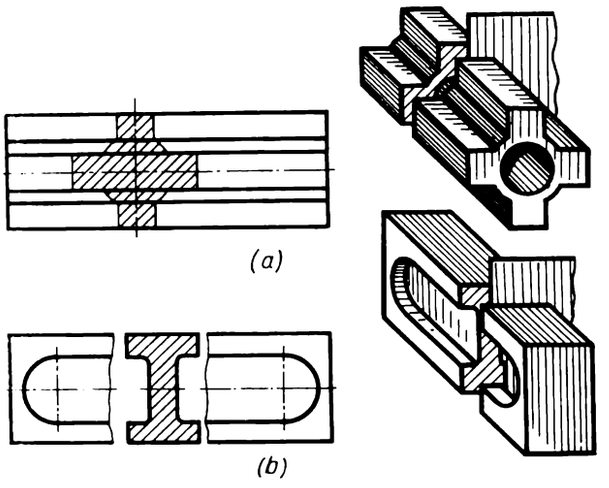


Fig. 335

an extra view is a revolved section. A revolved section is obtained by passing a cutting plane through a member perpendicular to one of the principal planes of projection and then revolving the cross section thus obtained about its own axis of symmetry until it is parallel to the plane of projection. In this position the section will show the true shape directly on that view. This method is particularly useful for structural shapes, spokes of wheels, arms, handles, and the like. An example of, a revolved section is shown in Fig. 335.

In Fig. 335*a* the revolved section is drawn with a thin continuous line, whose thickness is one-third (or less) of that of the visible outline; no breaks are made in this case in the appropriate view of the piece where the revolved section is placed.

Another type of revolved section is shown in Fig. 335*b*. Here the section is drawn in a break of the main view and has the same kind of contour lines.

Revolved sections are not commonly employed in machine drawing. Removed sections prove more convenient in most cases.

6. REMOVED SECTIONS

In complicated drawings it is frequently necessary to clarify the construction of certain parts of machine components when it is not desirable to make a full or half-section. This may be done by drawing what is known as a removed, or detail, section.

The principal difference between an ordinary sectional view and a removed section is illustrated in Fig. 336. As mentioned earlier, the removed section (Fig. 336*c*) shows only what is the cutting plane, while an ordinary sectional view (Fig. 336*d*) shows what is behind the cutting plane as well.

In the case of a removed section, the location and extent of the cutting plane are shown on the principal views by means of the usual symbol with arrows indicating the direction of viewing. The section is usually marked with a capital letter at each end of the cutting plane, as in Fig. 337 (Sections *A-A*, *B-B*, *C-C*). The actual section may then be drawn at some other place on the sheet either in alignment (as Section *C-C* in Fig. 337) or without any correlation with the views (as Section *B-B*, same figure). It can also be turned, as in Fig. 338 (section *A-A*), in which case an inscription *turned* should be added. The outline of a removed section is drawn with a continuous line of the same thickness as visible outlines.

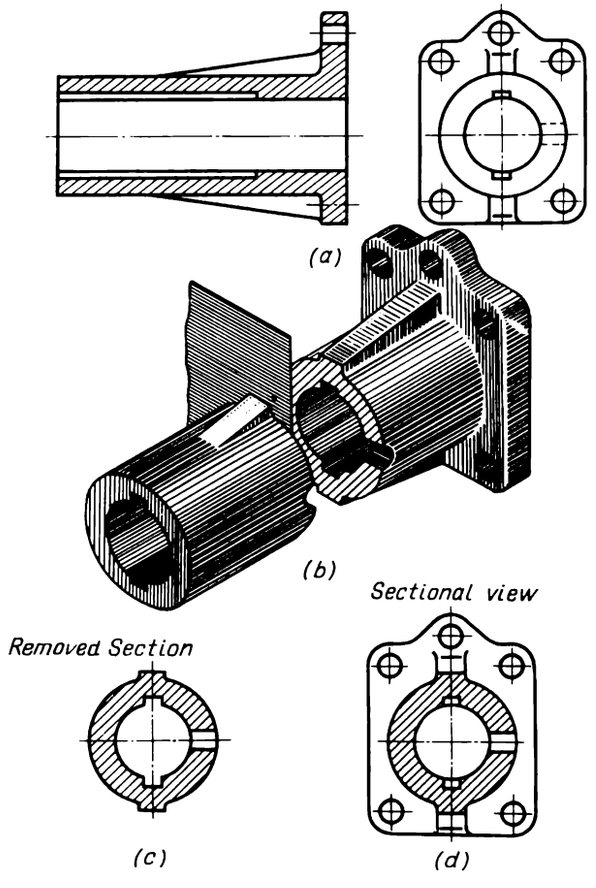


Fig. 336

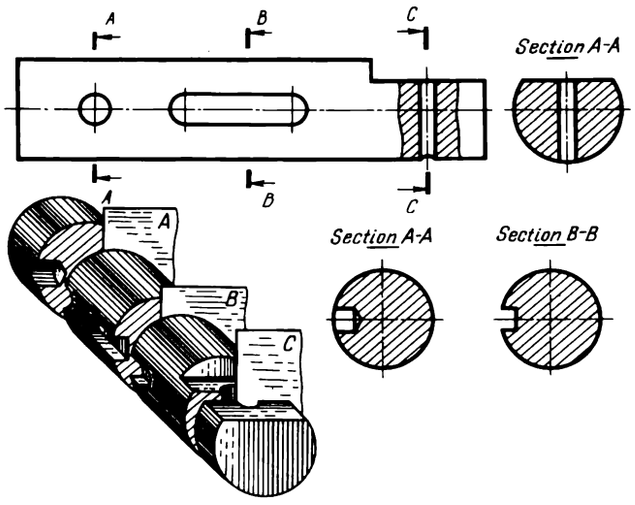


Fig. 337

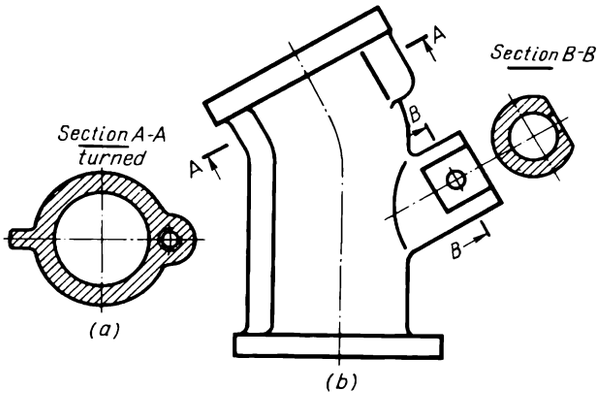


Fig. 338

Just as other sectional views, removed sections are cut by projecting planes, for instance, by a vertical projecting plane, and, as an exception, by a cylindrical surface.

The cutting planes should be chosen so as to obtain normal cross sections. If, for example, two cross sections of the branch pipe shown in Fig. 338 are required, then two cutting planes must be chosen, each being perpendicular (normal) to the extreme elements of the two cylindrical surfaces.

The USSR Standard provides for one exception from the general rule which states that a removed or revolved section should show only what lies directly in the cutting plane: if a cutting plane passes through the axis of a surface of revolution bounding holes of cylindrical or conic shape, then the contour of the hole or recess is shown completely (see Fig. 337, Sections *A-A* and *C-C;* compare them with Section *B-B* where the recess is not a surface of revolution).

Shown in Fig. 339 are various parts whose drawings should be completed with removed sections for clarifying the construction of certain elements. In Fig. 339*a* the section plane cuts across one of the spokes of the gear wheel.

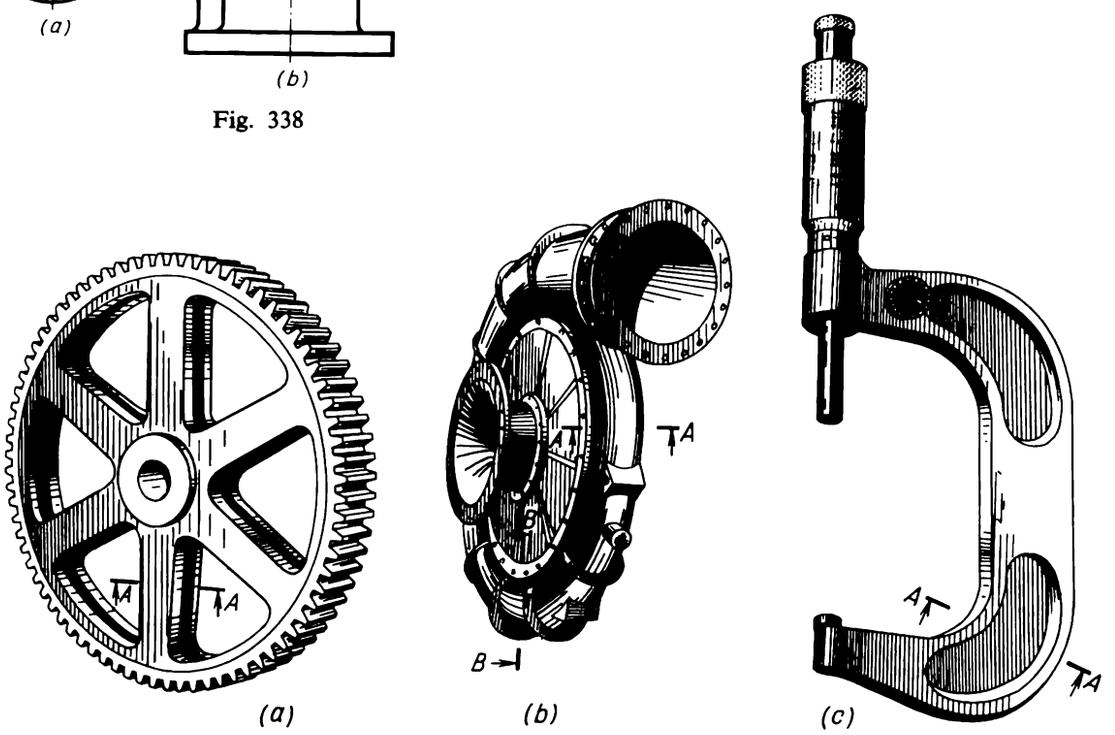


Fig. 339

In making a drawing of the casing of a centrifugal pump depicted in Fig. 339*b* a number of radial sections are required, since their shape and size differ from section to section (compare Section *A-A* with Section *B-B*).

A similar radial cutting plane is needed for orthographic representation of the micrometer gauge shown in Fig. 339*c* (Section *A-A*).

To conclude, one of the important advantages of the removed section is that the sectional views may be drawn to a much larger scale than the main views, thus showing the detail more clearly. The scale must be clearly indicated for each section, as shown in Fig. 331. Another advantage is that the main views showing the general outlines of the object are not confused by a large number of broken lines or cross section lines. A further advantage consists in the better-balanced drawing space, since cross-sectional views may be moved to any vacant place on the sheet.

7. CONVENTIONAL SYMBOLS USED IN SECTIONING

The kind of material should be indicated by using a specific type of section lining. The conventional symbols stipulated by the USSR Standard for various materials given in section are shown in Table 7.

If a material contains metals and non-metallic materials, then it is cross-hatched as a metal. Some parts used in electrical engineering, such as electromagnetic windings, coils, etc., are usually shown in section as a mesh. For conventional representation of sectioned sheet packs of rotors, stators, inductors, transformers, and choke coils see the appropriate standard.

In sectional views and removed or revolved sections the cut surfaces of objects are distinguished from other surfaces by cross-hatching, or section lining. This is done by using fine continuous parallel lines drawn at an angle of 45°

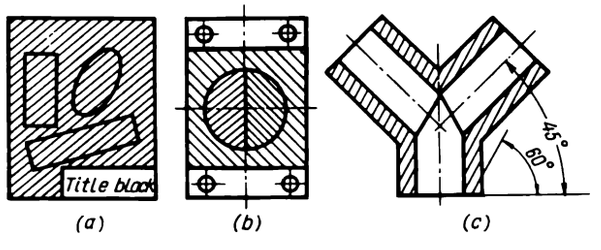


Fig. 340

Table 7

Symbol	Material
	Metals
	Non-metallic materials except those specified below
	Wood, across grain
	Wood, with grain
	Plywood
	Plain concrete
	Filled up ground
	Reinforced concrete
	Building brick
	Special brick (refractory, acid proof, etc.)
	Glass and other transparent materials
	Liquids
	Earth at edges of foundations

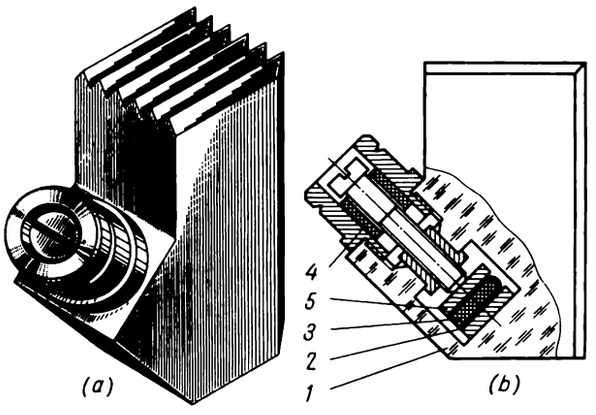


Fig. 341

to an axis or outline of the drawing, or to its title block (Fig. 340*a*).

If a part is so shaped that 45-degree sectioning runs parallel or nearly so to one of its outlines or axes, an angle of 30° or 60° may be used, as in Fig. 340*c*. In all cases it is desirable to make the cross-hatching in opposition to, or at least not parallel with, the outlines of the sectioned area.

The section lines may be inclined either to the left or right, but for sectional views and removed or revolved sections of the same part they must be inclined in the same direction and be equally spaced for all its sections drawn to one and the same scale. The spacing between the lines is measured by eye but should be uniform and thus attractive. It is usually between 2 and 10 mm depending on the area. Small areas may be section lined at 1.5 mm.

Long and narrow sections (less than 2 mm wide) may be cross-hatched freehand at intervals or even made solid black independent of the material. Wood, plywood, glass, and soil are also cross-hatched freehand.

For cross-hatching of adjacent parts see Fig. 340*b*.

A practical example of using conventional symbols for various materials given in section is illustrated in Fig. 341. Shown in the figure is the head of an ultrasonic flaw detector. According to the USSR Standard its individual parts should be cross-hatched in the following manner:

— prism *1* made of organic glass is represented as glass (see Table 7);

— plate *2* made of barium titanate (a metallic alloy) should be section lined as metal, but since its thickness is less than 2 mm, it is made solid black;

— damper *3* made of asbestos (mineral fibre) is cross-hatched as non-metallic material;

— bushing *4* made of hard rubber is shown in the same way as the damper;

— disk *5* made of steel is cross-hatched as metal.

8. CONVENTIONAL PRACTICE IN MACHINE DRAWING

The USSR Standard *Drawings in Mechanical Engineering* specifies various simplifications and conventionalities in making machine drawings.

The most common convention consists in the following. When a cutting plane passes through the longitudinal axes of solid cylinders such as shafts, bolts and screws, it is considered that these parts are not cut by the section plane. Nothing would be gained by showing the solid interior of such parts, and a great deal of time is saved by eliminating large areas of cross-hatching. Such elements as thin walls, webs, stiffening ribs, lugs, pulleys, handwheels, spokes and teeth of gears, etc., also come under this rule.

Illustrated in Fig. 342*a* is a step bearing cut by a frontal plane, Fig. 342*b* showing its vertical sectional view and the plan. Its stiffener is not cross-hatched even though the cutting plane passes through its longitudinal axis. If solid parts have recesses, blind or through holes, etc., the latter are shown by making broken-out sections, as in Figs. 343 and 3 '4.

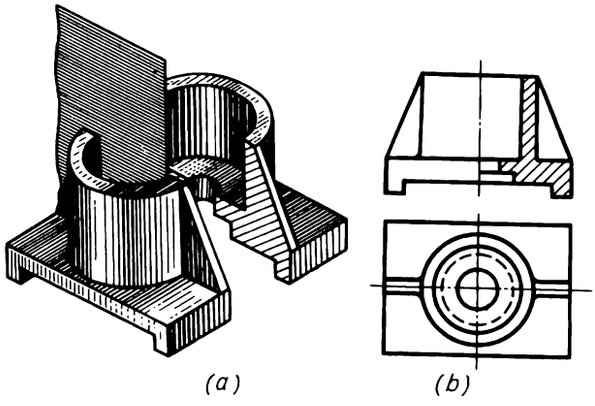


Fig. 342

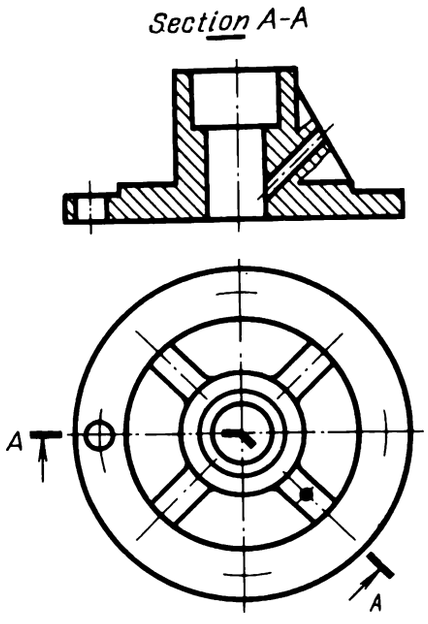


Fig. 343

The pin in Fig. 344 has a short bore along its axis. You need not section line the whole view, a broken-out section will reveal the hidden element.

Here are two more examples (Fig. 344): an axial sectional view of a gear and a longitudinal section of a frame. The spokes, teeth, stiffener and lug should not be cross-hatched.

In passing a section plane through such objects as a flange (Fig. 345*a*) or a flywheel (Fig. 345*b*) it is conventional practice not to show the web behind the cutting plane and to represent the spoke as if turned to coincide with the section plane.

This rotation of parts, though not in strict accord with the theory of orthographic projection, is so commonly used that it has come to be recognized and accepted as standard practice. It is used on both sectioned and unsectioned drawings.

For the sake of simplicity only one of the holes spaced equally round a circle is shown on a view, the rest of them being conventionally replaced with their centre lines, as in Fig. 345*a*.

If a machine part has planes of symmetry, then one of its views may conventionally present two sections, both of them being complex, or one complex and the other simple, as in Fig. 346. The bearing housing shown in the figure is cut by profile planes to obtain two sectional half-views on the profile plane of projection: an offset section *A-A*, and a simple section *B-B*.

Lines of intersection of certain surfaces may be represented in a simplified manner on mechanical drawings. Two examples are given in Fig. 347, where instead of the curved lines of intersection of two cylindrical surfaces of the holes straight lines are drawn.

Furthermore, instead of drawing a full view one-half is sufficient, as in Fig. 347*a* and Fig. 348.

In representing holes and keyways in gear hubs, pulleys, couplings, flywheels, etc., a single view will do. It is also permissible to draw only the contour of a hole or keyway, as is illustrated in Figs. 347*b* and 349.

An important element of an object (Fig. 350) situated between the viewer and the cutting plane may be shown on a sectional view with a dot-and-dash line as a superimposed projection.

Figure 351*a* and *b* indicates the conventional practice in representing gradients and tapers.

Transition lines between surfaces gradually merging into each other are shown conventionally or not shown at all (see Fig. 352*a*).

Cut and knurled surfaces of machine parts are shown conventionally, as in Fig. 352*b*. Only a certain portion of such a surface is covered with the specific symbol.

If a part has several similar elements spaced equally round a circle (for instance, spokes of wheels or flywheels), then only one such element is shown on external and sectional views, with an inscription indicating the total number of elements, as in Fig. 353.

Questions

1. How are views arranged in an orthographic drawing according to the USSR Standard?
2. When are the direction of the cutting plane and the designation of the section not indicated on a sectional view?
3. What are the conventional symbols for various materials in section according to the USSR Standard?
4. How many views are required to represent a machine part?
5. Why and how are auxiliary views facing arrows drawn?
6. What are the alternative arrangements of

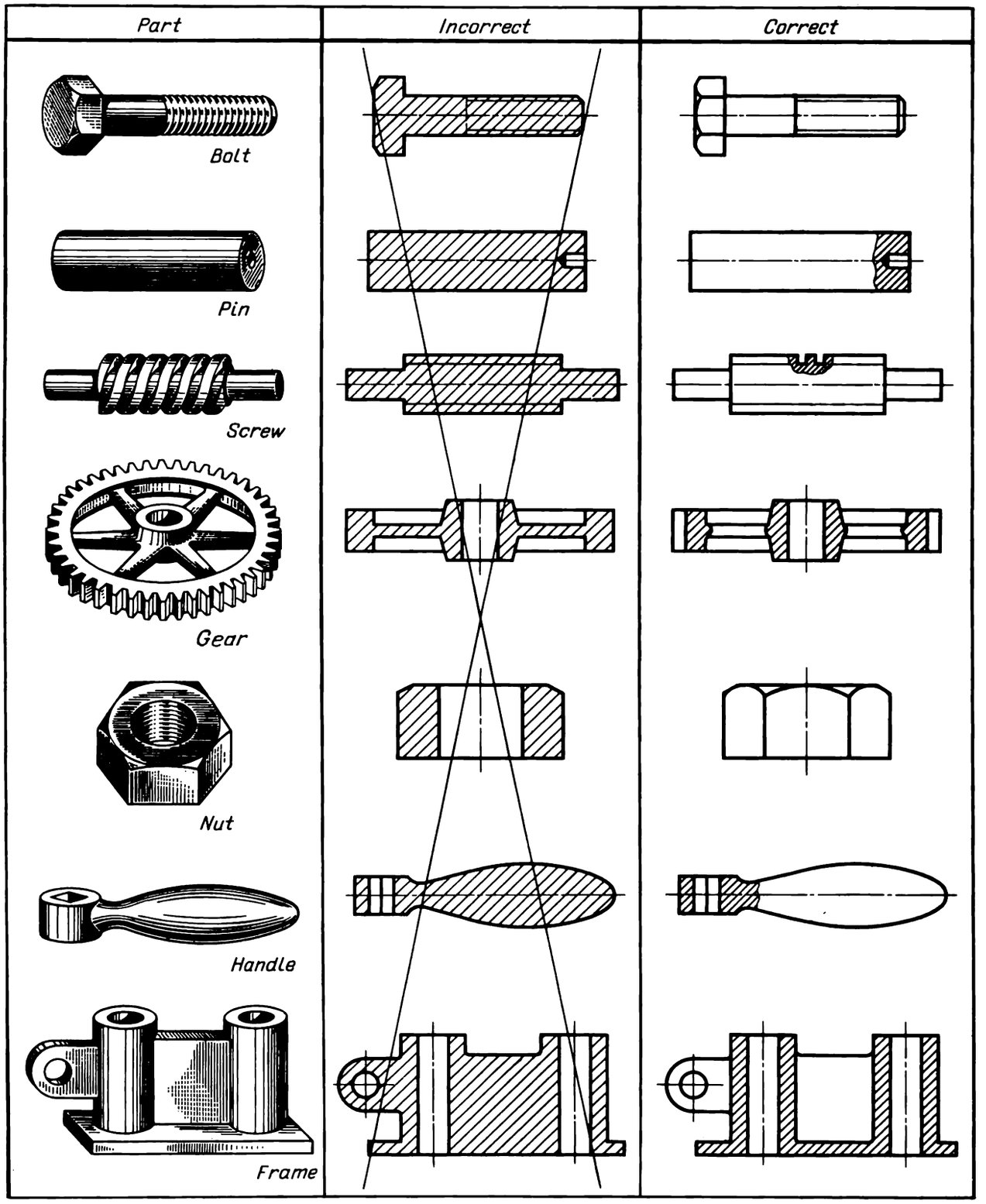
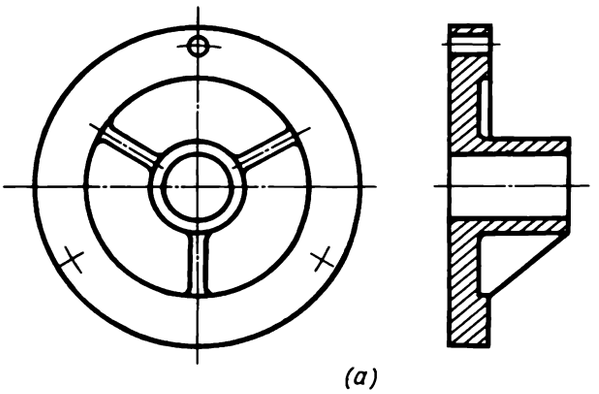

Part
Incorrect
Correct
Bolt
Pin
Screw
Gear
Nut
Handle
Frame

Fig. 344



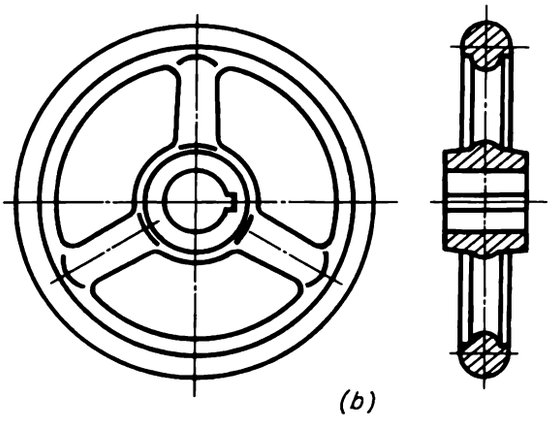


Fig. 345

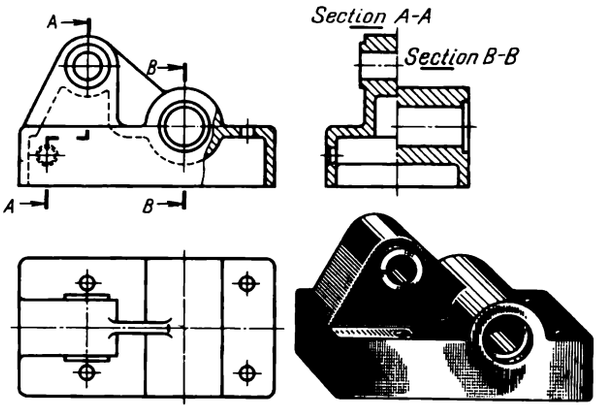


Fig. 346

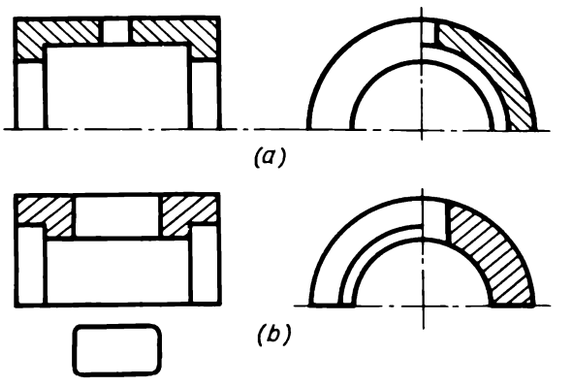


Fig. 347

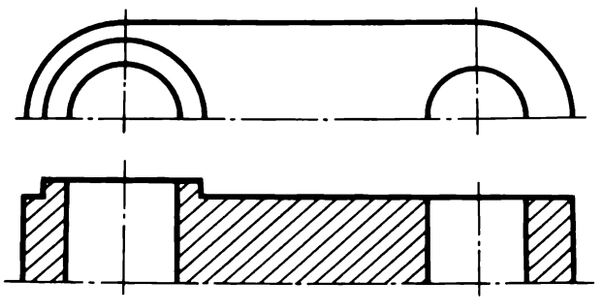


Fig. 348

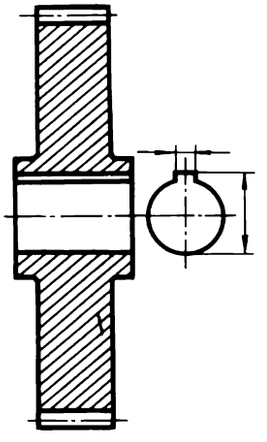


Fig. 349

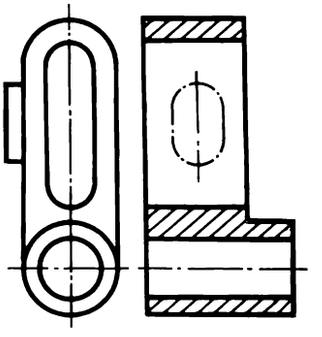


Fig. 350

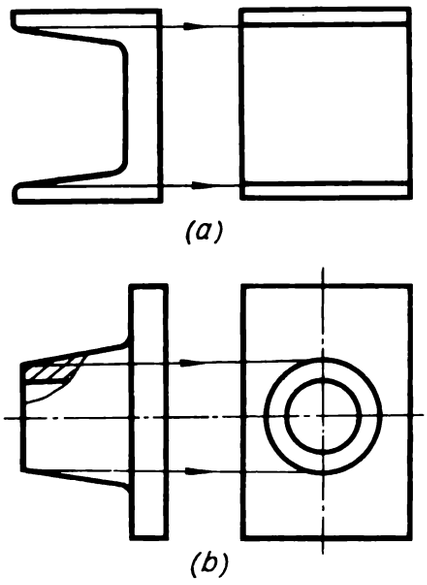


Fig. 351

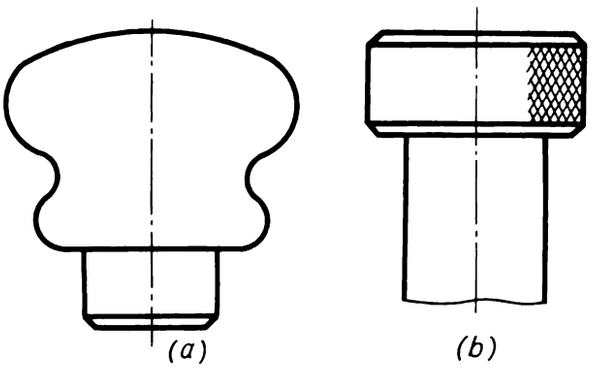


Fig. 352

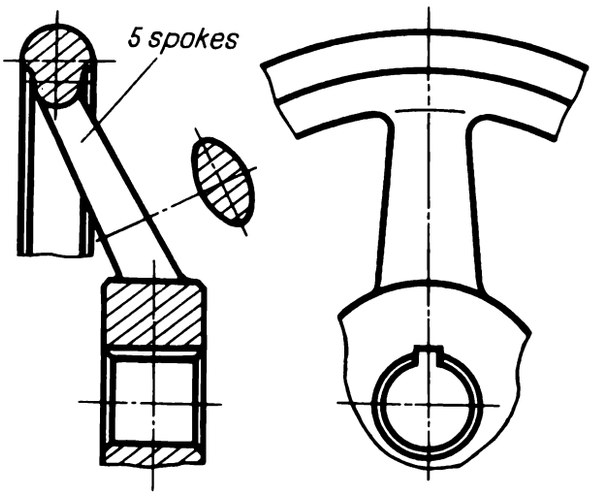


Fig. 353

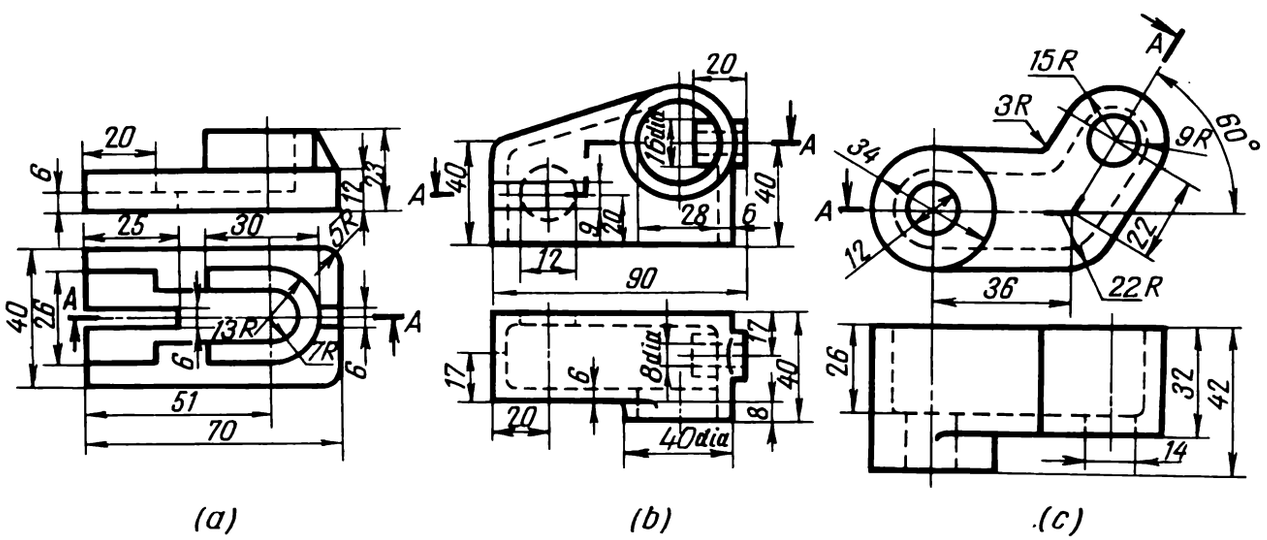


Fig. 354

the principal views on a drawing allowed by the USSR Standard?

7. What inscriptions and instructions are given on a drawing when making views facing arrows?

8. What are the exceptions from the rules for making sections in machine drawings?

9. When are local views and various kinds of sections used?

10. What is a removed element? Its purpose and scale?

11. What is the difference between revolved and removed sections?

12. When is an inscription *Turned* made?

13. What elements and of what machine parts are not cross-hatched in longitudinal sections?

Exercise 62

Make sectional views as shown in Fig. 354*a*, *b* and *c*.

CHAPTER 3

HELICAL SURFACES AND THREADS

Threaded products incorporating helical surfaces are divided into two groups:

1. Fasteners, designed for holding together the various parts of a structure — bolts with nuts, screws, studs, etc. (Fig. 355).

2. Various kinds of screws and worms, designed to transform rotary into translational motion — motion screws, conveyor worms, lifting screws, etc. Fig. 356 gives two examples of the practical application of screws: a valve (Fig. 356*a*) and a tension station of a conveyor (Fig. 356*b*).

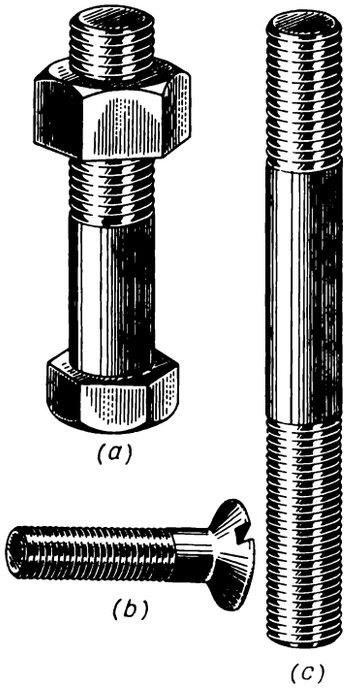


Fig. 355

Classified as a separate group are parts with helical surfaces used for various purposes, such as conveyor screws (Fig. 357*a*), worm gearing

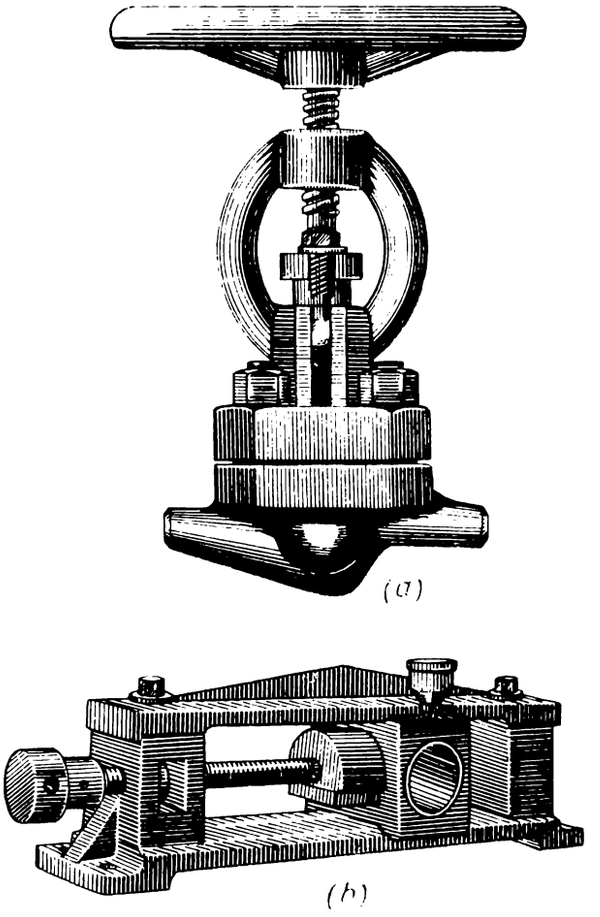


Fig. 356

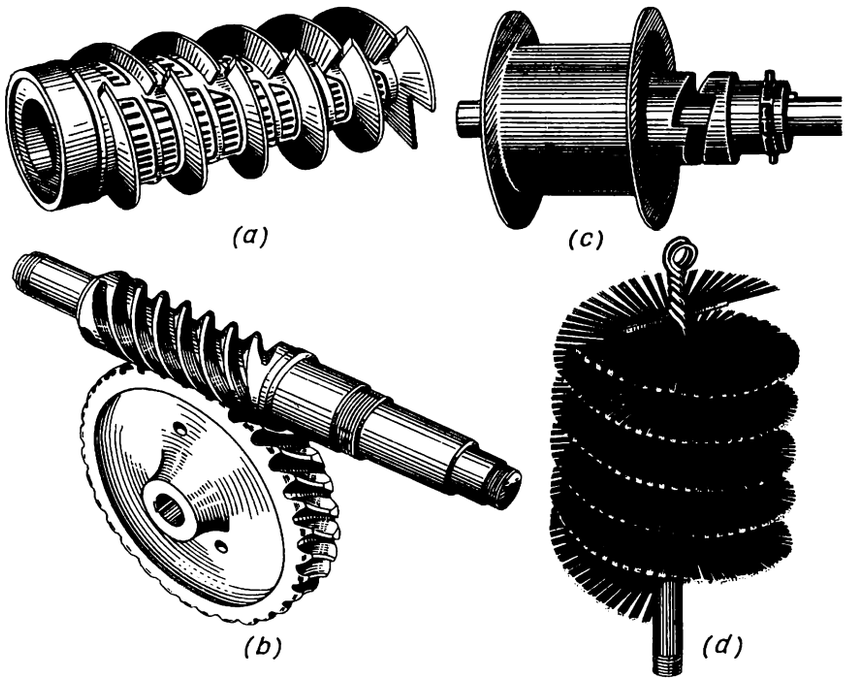


Fig. 357

(Fig. 357*b*), jaw clutches (Fig. 357*c*), and brushes for cleaning fire tubes of steam boilers (Fig. 357*d*).

1. CONSTRUCTING HELICES AND HELICAL SURFACES

The construction of a helical surface on a drawing is usually reduced to construction of several turns corresponding to the crests of a screw surface.

Any helical surface can easily be represented by using the method of constructing a helix.

Consider the method of constructing a helix on a right circular cylinder with a vertical axis.

Let us take a flexible right triangle ABC (Fig. 358) with the larger leg AC equal to the circumference πD of the cylinder, the smaller leg equal to the helix lead or pitch p (see further), and the vertex A lying on the surface of this cylinder. Wrap the triangle round the cylinder, then the hypotenuse AB, brought into coincidence with the cylindrical surface, will form a helix.

From the geometrical point of view this is a curve generated by a point A moving on the surface of a cylinder (or cone) in a circumferential direction, at a constant angular speed, and with a simultaneous uniform rate of advance in an axial direction.

A helix, or thread, that advances into engagement in a direction away from the observer when turned in a clockwise direction is called right-hand (Fig. 358*a*); one that advances into engagement in a direction away from the observer when turned in an anticlockwise direction is called left-hand (Fig. 358*b*).

A helix can be obtained on a cylinder in the following way: clamp a cylindrical rod in the chuck of a lathe and set it into uniform rotary motion; bring a thread tool into contact with the cylinder and set it into uniform forward motion along the cylinder axis (Fig. 359); the point of the tool will draw a helix on the surface of the cylinder.

If the cylinder were developed, the helix would become the hypotenuse of a right triangle whose base is the circumference of the cylinder (πD) and altitude, the lead of the helix (p). The angle between the hypotenuse and the base of the triangle is known as the helix angle α. The tangent of this angle is equal to the lead divided by the circumference of the helix cylinder, i.e.,

$$\tan \alpha = \frac{p}{\pi D}$$

whence

$$p = \pi D \tan \alpha$$

To construct a helix the circumference of the cylinder of diameter D must be divided into several equal parts (e.g., 16 for convenience) numbered in the direction of rotary motion of the point generating the helix (Fig. 360). The lead p is also divided into 16 equal parts which are numbered from the bottom upwards. Then through the points of division of the lead draw horizontal lines and project on them the corresponding points of division of the circle.

In this way we can construct right- and left-hand helices on the surface of the parts shown in Fig. 357.

A helical surface is generated by the helical motion of a line, which is called the generatrix

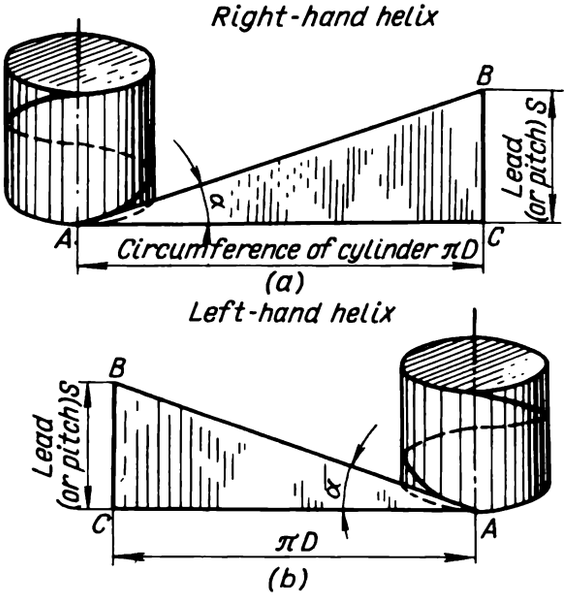


Fig. 358

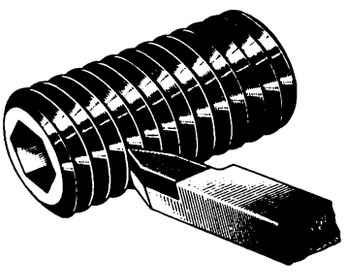


Fig. 359

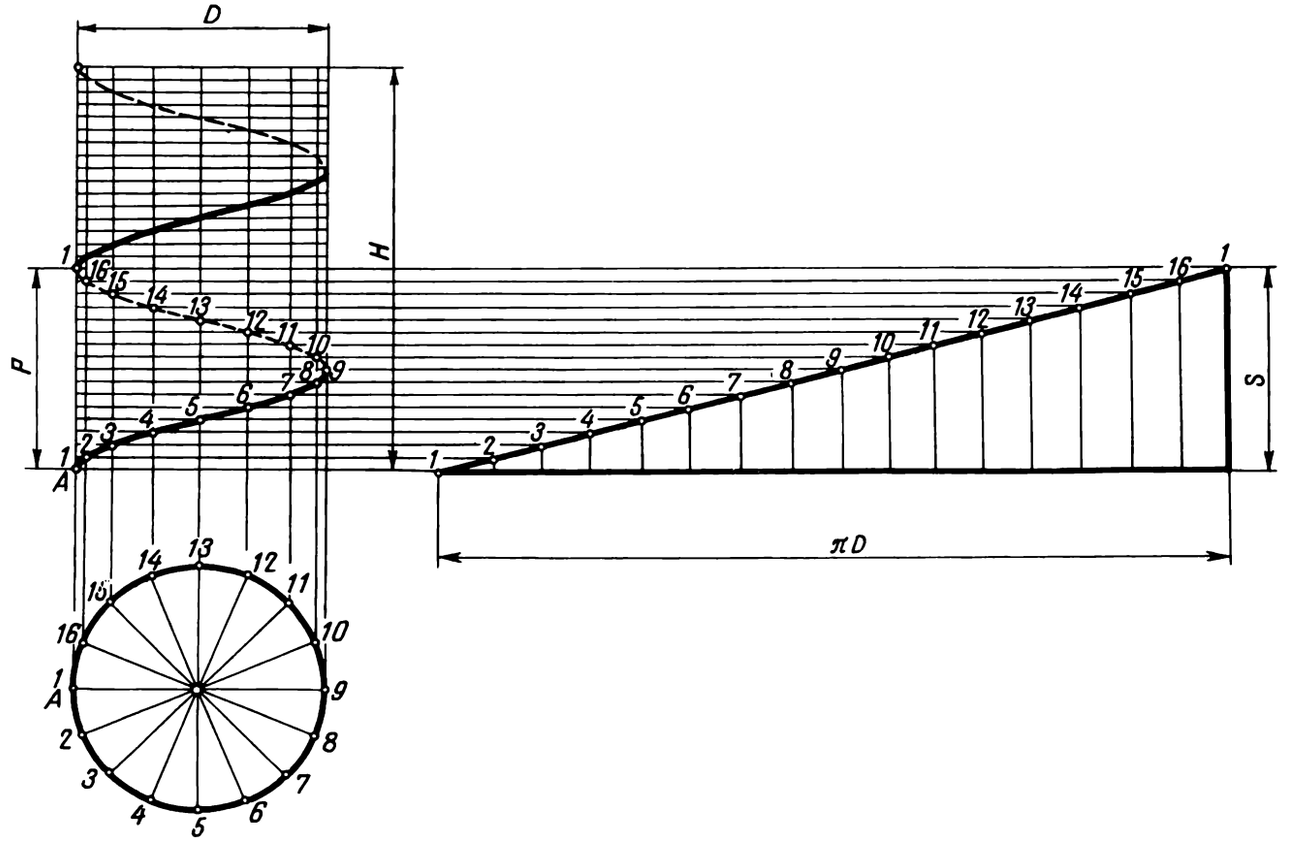


Fig. 360

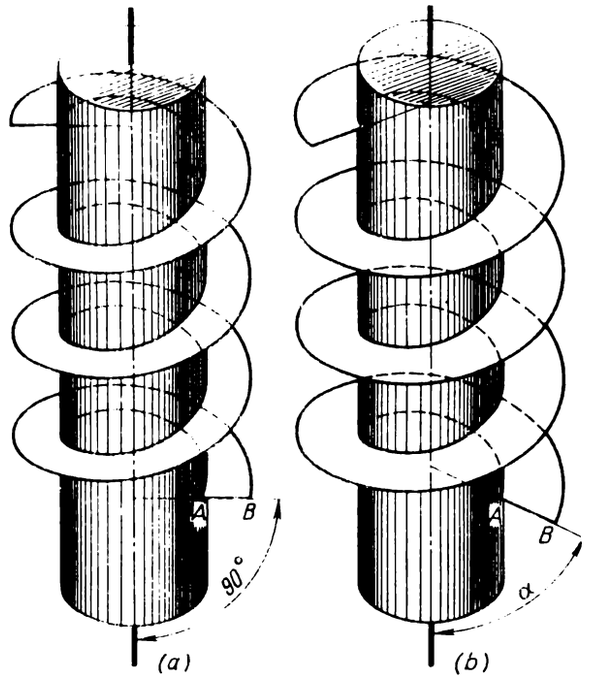


Fig. 361

of the surface. By helical motion is ordinarily meant motion representing a combination of two motions: translational (parallel to a certain axis, the screw axis) and rotational (about this axis).

If helical motion is performed by a straight line, the surface will be helical. If the generatrix *AB* (Fig. 361*a*) intersects the screw axis at a right angle, we have a right helicoid. The right helicoid is used in spiral stairways and ramps (in multistorey garages, for instance). The surface of a railway bed on an upgrade curve is also a right helicoid. An example of such a surface is shown in Fig. 357*c*, where the back of the clutch jaw is a *right helicoid.*

If the generatrix *AB* is inclined to the screw axis at an angle α the surface generated is called an *oblique helicoid* (Fig. 361*b*).

The brush for cleaning fire tubes of steam boilers shown in Fig. 357*d* is an example.

If two points, whose initial positions are at the opposite ends of the base circle diameter, perform helical motion on the surface of a cylinder in the same direction, then a *double helix*, or *double thread* is obtained (Fig. 362). When two or more separate threads on as many parallel helices are wrapped around a cylinder we have a *multiple thread.* In this case the points performing helical motion are arranged in their initial position at angular distances of 180°, 120°, 90°, etc.

The purpose for which the screw is to be used will frequently determine the shape or profile of the thread.

Cylindrical threads are divided into fastening threads and special-purpose threads.

The *fastening threads* comprise *metric threads* (coarse and fine) and *inch threads.* The profile of a metric thread is an equilateral triangle (60° thread angle), while that of an inch thread is an isosceles triangle with a vertex angle of 55°.

The *special-purpose threads* are: pipe, trapezoidal, buttress, knuckle, square, and certain others. Straight pipe thread is used on pipes and fittings of pipelines. The profile of such a thread is a triangle.

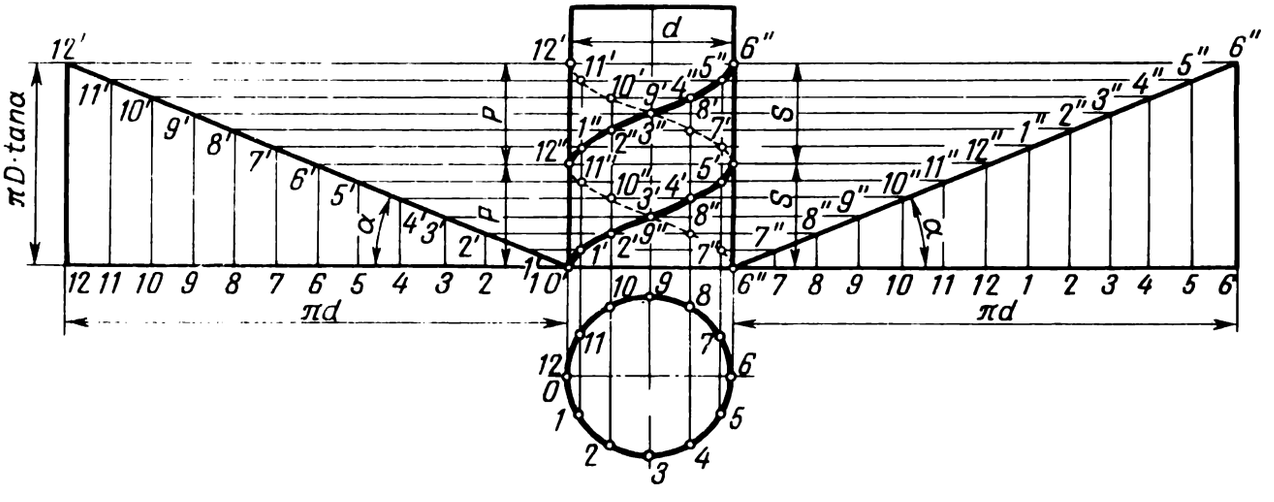


Fig. 362

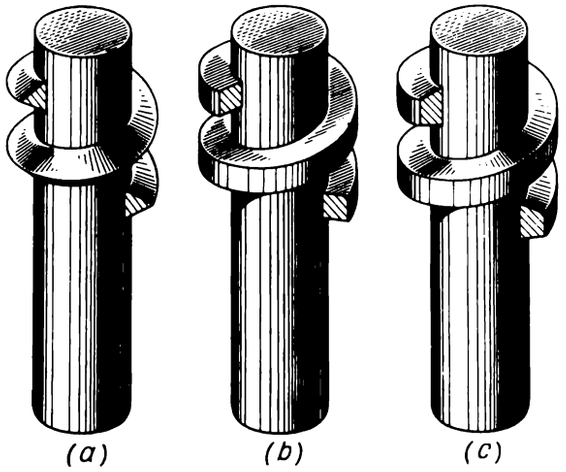
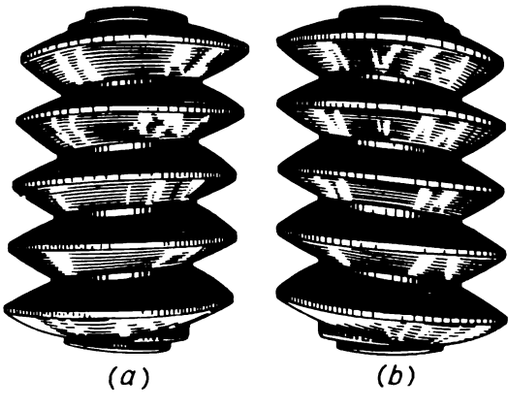


Fig. 363



Illustrated in Fig. 363 are screws with different thread profiles: triangle, or sharp-V (Fig. 363*a*), square (Fig. 363*b*), and trapezoidal (Fig. 363*c*). Shown in Fig. 364 are screws with a right-hand (at *a*), and left-hand (at *b*) thread.

Fig. 364*c* illustrates a triple-thread screw with a square thread profile, Fig. 364*d* portrays a six-thread nipple, the six vertices of the hexagon being the starting points for the six helices.

The distance from a point on a screw to the corresponding point on the next thread measured parallel to the axis is called the *pitch*. The distance (t_s) a screw thread advances axially in one turn is its *lead*.

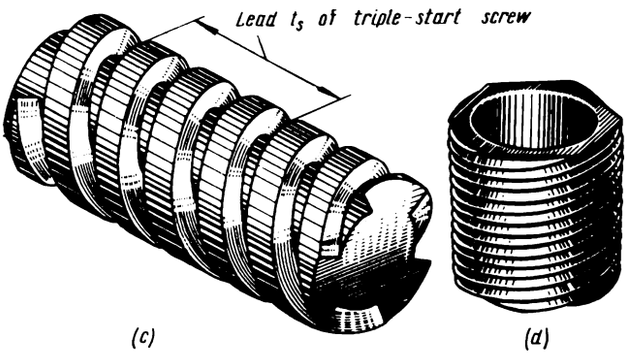


Fig. 364

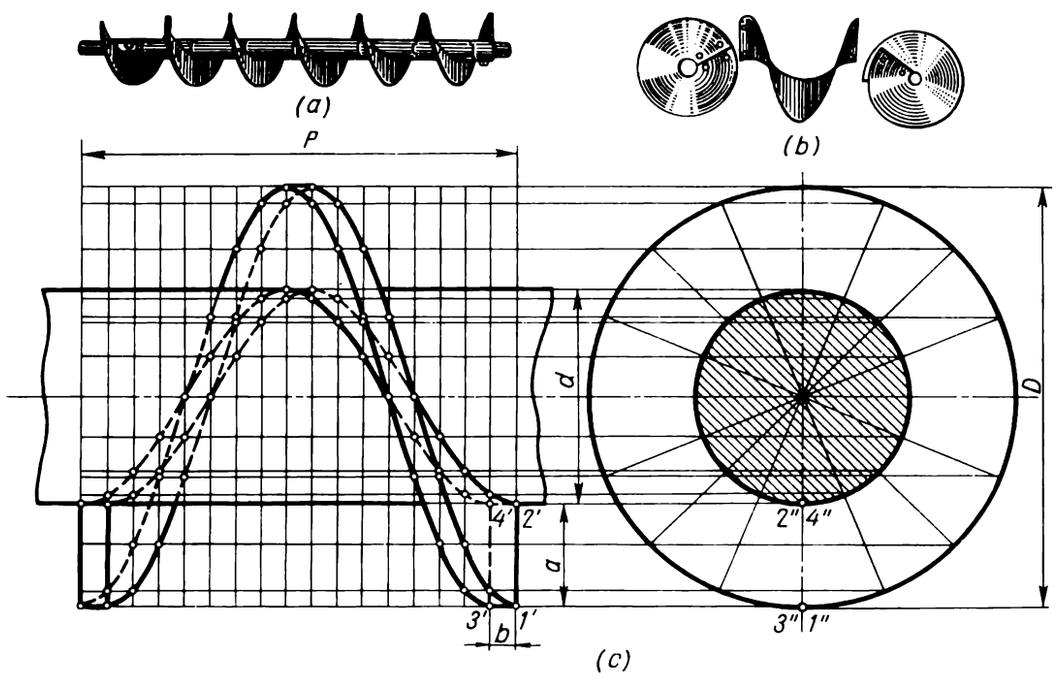


Fig. 365

On a single-thread screw, the lead and pitch are identical; on a double-thread screw, the lead is twice the pitch; on a triple-thread screw three times the pitch, etc. Thus, for a screw having z threads, the lead t_s is equal to the pitch p multiplied by the number of threads, i.e., $t_s = pz$.

Constructed in Fig. 365*a* is the surface of the worm of a worm conveyor used for transporting cement, sand, coal, and other bulk materials. In manufacturing the worm its separate elements (Fig. 365*b*) are assembled by electric arc welding.

Given:

(1) direction of the helix: right-hand;

(2) thread profile: rectangular (Fig. 365*c*) with the sides of the rectangle equal to a and b (mm);

(3) diameter of the cylinder: d (mm);

(4) pitch of the thread: p (mm);

(5) number of threads: $z = 1$.

Sequence of construction:

1. Construct two orthographic views (the vertical and profile projections) of the given cylinder.
2. Construct the vertical projection of the thread profile, i.e., of rectangle *1-2-3-4* touching the cylindrical surface with its side equal to *b*.
3. Construct a helix for point *1* of the profile; this helix will be found on the cylindrical surface of diameter $D = d + 2a$ and will have the same pitch p.
4. Construct a helix for point *2*.
5. Construct a helix for point *4*.
6. Construct a helix for point *3*.

A screw with a square profile (Fig. 366*a*) is constructed in the same manner. Such screws are frequently used in lifting and feeding devices.

Constructed in Fig. 366*b* is a right-hand single-thread screw with a square profile cut by a horizontal plane *A-A*.

As is seen from the horizontal projection of the screw, the section comprises only the front portion of the thread, the rear portion not being cut by the section plane.

A screw surface with a triangular thread profile is constructed in Fig. 367. Given are: major diameter of the thread d, minor diameter d_1, pitch p. It is a single-thread screw with a right-hand helix, the base of the profile triangle being equal to the pitch of the screw. Proceed as follows.

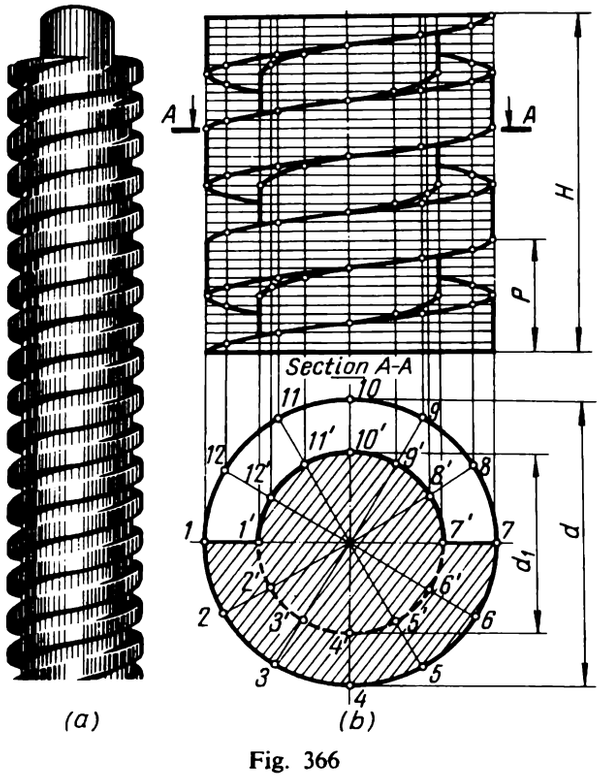


Fig. 366

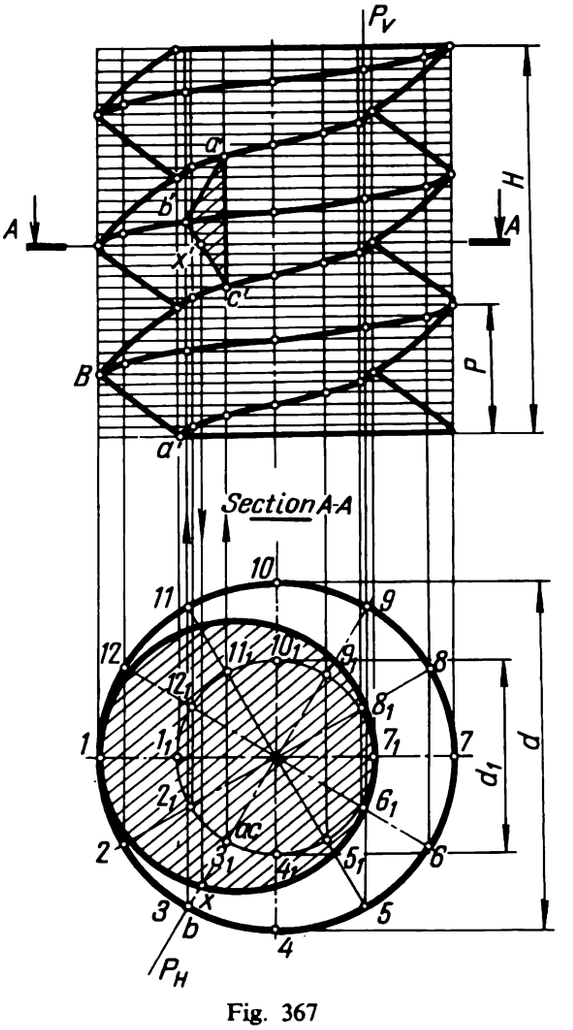


Fig. 367

Divide both circles (of diameters d and d_1) on the plan into any number of equal parts (e.g., 12 for convenience) and denote the points of division by figures increasing anticlockwise, i.e., in the direction of the point generating the given helix.

Mark off the length p along the axis on the vertical projection of the screw and divide it also into 12 equal parts.

Construct a helix generated by the point A moving on the cylinder of diameter d_1 by directly projecting the points of division of the circle d_1 onto the horizontal lines passing through the points of division of the pitch. The helices generated by the points B and C are constructed in the same way.

The contour of the screw is conventionally drawn as lines tangent to the two constructed sine curves (for instance, $a'B$ on the vertical projection).

Section A-A cut by a horizontal plane is bounded by a closed curved line following the spiral of Archimedes. To determine the points belonging to this curve a series of auxiliary cutting planes perpendicular to the plane H are passed through the axis of the screw (for instance, the plane P_H). Each of the planes will cut a profile triangle (say, ABC) from the screw surface. The horizontal projection of this triangle is a portion cb of the radial line located between the two concentric circles (d and d_1). The vertical projection of the triangle is found by projecting the end points of this line-segment onto the corresponding helices. The point of intersection of the constructed vertical projection of the triangle (to be more precise, of its side $b'c'$) with the cutting plane A-A will be the required point x on the helix, which is then projected onto the horizontal trace P_H of the auxiliary cutting plane.

Screws with a triangular, or V-shaped, profile are widely used in mechanical engineering. Almost all fasteners have this thread profile.

2. THREADS AND THREAD REPRESENTATION IN DRAWINGS

In drawings threads are not drawn true to life. It would require much time and work to draw a thread as it really is. Moreover, as is clear from the following, threads are not tapped

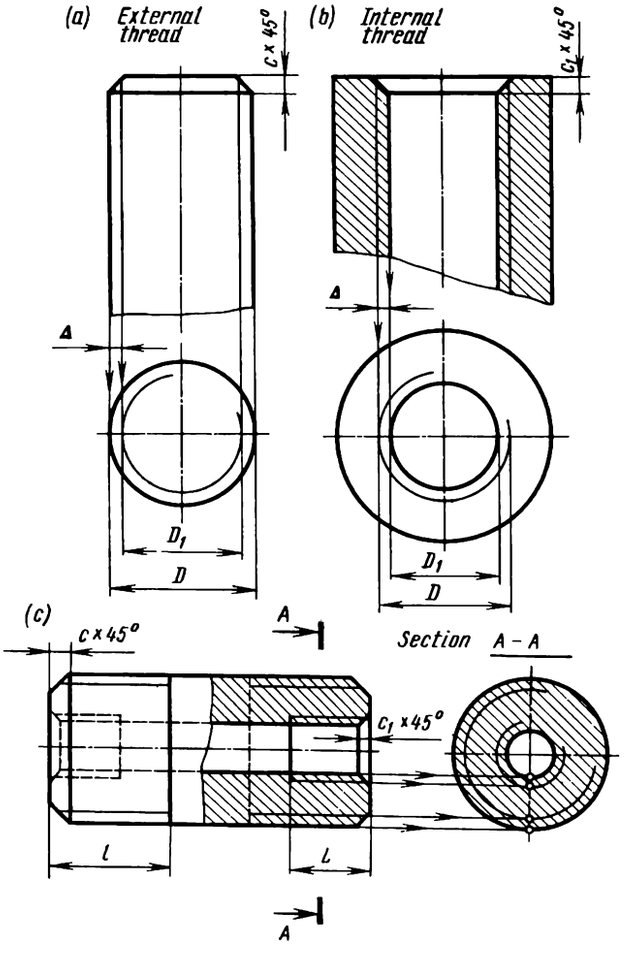


Fig. 368

from drawings and therefore drawings give but simplified conventional representations of threads, as illustrated in Fig. 368.

A simple method of drawing external thread consists in the following. The outline of the rod, etc., corresponding to the major diameter of the thread is drawn in continuous straight lines (see Fig. 368*a*). Lines corresponding to the minor diameter of the thread (or lines of the roots) are drawn as short dash lines.

The beginning and end of the thread are represented by continuous visible outlines.

Internal thread in sectional views is represented by continuous visible (the minor diameter) and dash (the major diameter) lines, as shown in Fig. 368*b*.

Threaded holes on top views are represented by a continuous visible line (the minor diameter) and a fine-line arc of about three-fourth of the major-diameter circle (Fig. 368*c*).

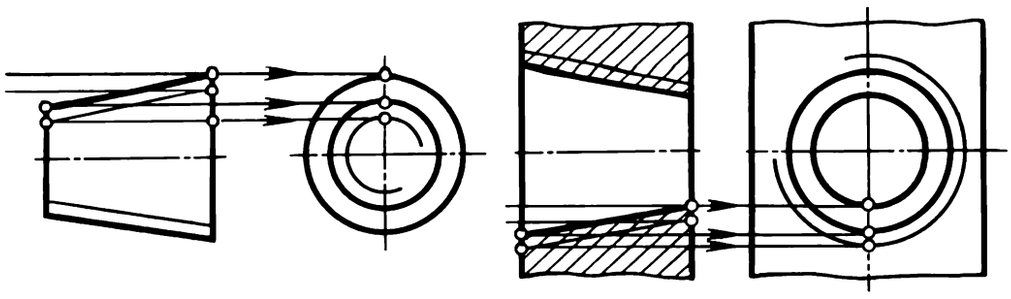


Fig. 369

Chamfers on such views are not shown.

A taper thread is represented by three (instead of four) concentric circles, as in Fig. 369.

Let us consider various thread forms in common use shown in Fig. 370.

(1) *Metric thread* with a sharp-V profile (Fig. 370*a*) has found wide application (both right- and left-hand versions) in making bolts, screws, studs, nuts, and other fasteners. This thread is standardized and is cut on cylindrical and taper rods. Its profile is composed of a series of equilateral triangles truncated at the top, the thread angle being equal to 60° (see Fig. 370*b*).

Also standardized are metric threads for diameters from 0.25 to 0.9 mm, metric threads for instruments, and metric threads for diameters from 1 to 180 mm, applicable to parts made of plastics.

Metric threads may be coarse or fine, depending on the purpose.

A fine metric thread differs from a coarse metric thread of the same major diameter in that its pitch and depth are smaller than those of the latter.

For instance, the following pitches are specified for a major diameter of 30 mm: 3.5 mm (coarse pitch); 3.2 mm, 1.5 mm, 1 mm, and 0.75 mm (fine pitches).

In drawings we use special inscription called thread specifications, or standard forms to indicate the type of thread and its main dimensions (diameter, pitch, etc.). These specifications are written in breaks in dimension lines or above a dimension line drawn near the representation of the thread. Dimension lines for threads on cylindrical rods and inside holes always indicate the major diameter of the thread. According to the USSR Standard fine metric threads are specified not only by the major diameter but by the pitch as well. For a correct choice of the diameter and pitch of a metric thread use Table 8.

(2) *Inch thread* has a 55° triangular profile (Fig. 370*b*), and is measured in inches (1 inch= 25.4 mm). This is also a standardized thread (see Table 9) but is used only in manufacturing spare parts, since in designing new products in the USSR metric thread is employed throughout.

(3) *Cylindrical pipe thread* cut at 55° (Fig. 370*c*) with a pitch considerably smaller then that of inch thread. The dimensions of pipe

Table 8

Diameters and Pitches for Metric Threads According to the USSR Standard

(Dimensions in mm)

Diameter *d*			Pitch *p*	
1st series	2nd series	3rd series	coarse	fine
10	—	—	1.5	1.25, 1, 0.75, 0.5
—	—	11	1.5	1, 0.75, 0.5
12	—	—	1.75	1.5, 1.25, 1, 0.75, 0.5
—	14	—	2	1.5, 1.25, 1, 0.75, 0.5
—	—	15	—	1.5, 1
16	—	—	2	1.5, 1, 0.75, 0.5
—	—	17	—	1.5, (1)
—	18	—	2.5	1.5, 1, 0.75, 0.5
20	—	—	2.5	2, 1.5, 0.75, 0.5
—	22	—	2.5	2, 1.5, 1, 0.75, 0.5
24	—	—	3	2, 1.5, 1, 0.75
—	—	25	—	2, 1.5, 1
—	—	(26)	—	1.5
—	27	—	3	2, 1.5, 1, 0.75
—	—	28	—	2, 1.5, 1
30	—	—	3.5	(3), 2, 1.5, 1, 0.75
—	—	(32)	—	2, 1.5
—	33	—	3.5	(3), 2, 1.5, 1, 0.75
—	—	35	—	1.5
36	—	—	4	3, 2, 1.5, 1
—	—	38	—	1.5
—	39	—	4	3, 2, 1.5, 1
—	—	40	—	(3), 2, 1.5, 1 4

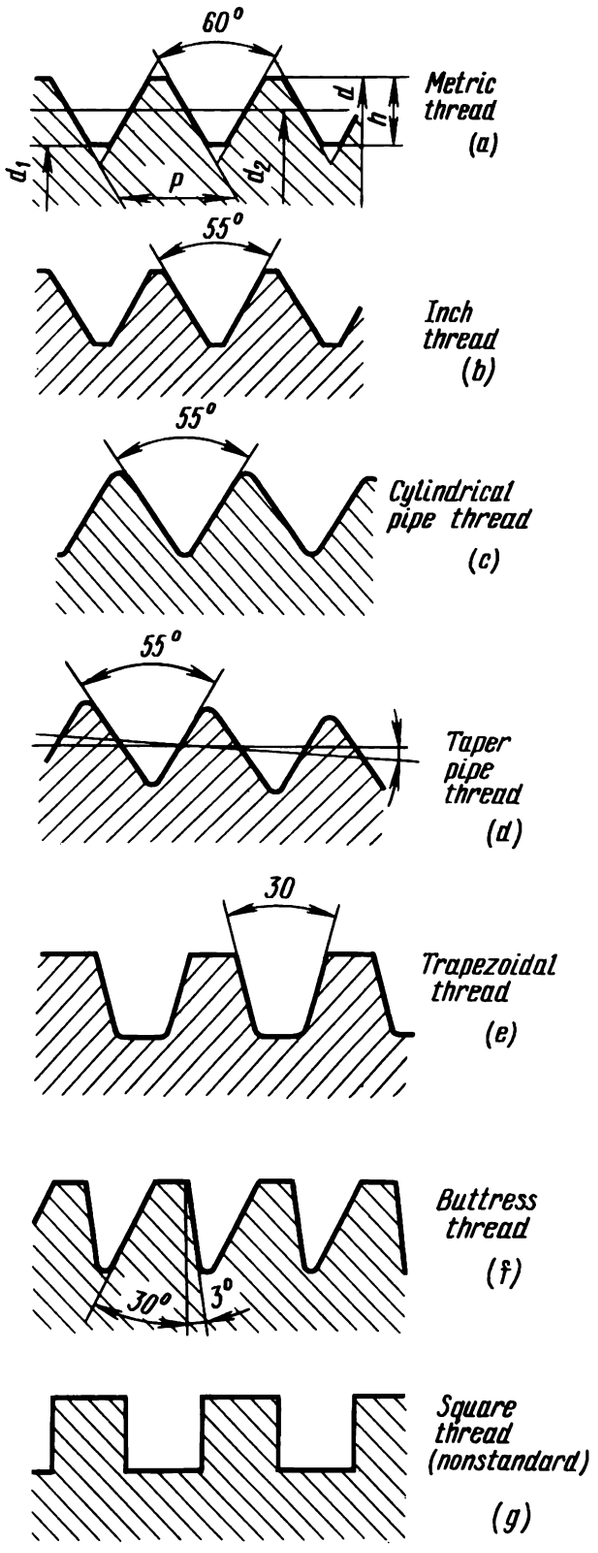


Fig. 370

Table 9

From the USSR Standard

(Dimensions in mm)

Thread designation in inches	Thread diameter		Pitch p	Number of threads per 1", n
	major d_0	minor d_1		
1	33.250	30.292	2.309	11
1 1/4	41.912	38.954	2.309	11
2	59.616	56.659	2.309	11

thread are tabulated in the appropriate standard. When using these tables remember that the first column contains conventional sizes of the thread in inches. The nominal size in inches relates to the conventional inside diameter, d_1, of the pipe on whose outside surface the thread is cut. An example of standard designation for a cylindrical pipe thread is given in Fig. 368*c*: *Pipe 1 1/4"*, where *pipe* indicates pipe thread, *1 1/4"* is the conventional thread size. The major and minor diameters of this thread are taken from Table 9 which is from the USSR Standard. In this case $d_0=41.912$ mm and $d_1=38.954$ mm.

The diameter of a taper pipe thread (Fig. 370*d*) is equal to the diameter of the corresponding cylindrical pipe thread measured in the reference plane. An example of designation is *T Pipe 1/2"* the USSR Standard, where *T* stands for taper, *Pipe* for pipe thread, *1/2"* is the major diameter measured in the main plane and equal to 20.9 mm. Since there is no indication as to the direction of the thread, the latter is assumed to be a right-hand thread.

Shown in Fig. 371 is a pipe connection whose taper end is screwed into a pneumatic cylinder (the latter is drawn in a thin continuous line).

(4) *Trapezoidal thread* is used in motion screws according to the USSR Standard (Fig. 370*e*). Its profile is a series of trapezoids with an in-

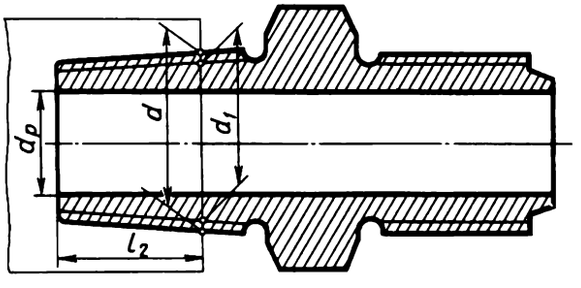


Fig. 371

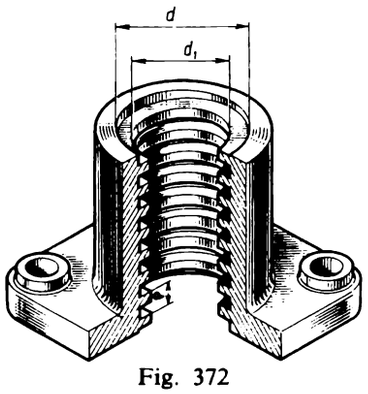


Fig. 372

cluded angle of 30°. Table 10 is from the standard specifying this type of thread.

(5) *Buttress thread* has a profile composed of a series of non-equilateral trapeziums with an angle of 33° (Fig. 370*f*).

When utilizing threads with non-standard profiles (Fig. 372) the thread profile must be shown (as in Fig. 370*g*), or a removed element given, the thread being dimensioned in the usual way.

Table 10

From the USSR Standard
(Dimensions in mm)

Diameter *d*			Pitch *p*		
1st series	2nd series	3rd series			
32			10	6	3
		34	10	6	3
	36		10	6	3
		42	10	6	3
60			12	8	3

3. VANISH THREADS, NECKS AND CHAMFERS

The most common tools used for making threads are: thread tools (Fig. 373), round dies (Fig. 374), taps (Fig. 375), flat rolling dies (Fig. 376*a*), and cylindrical dies (Fig. 376*b*).

To ensure a free exit of the cutting edge of the tool at the end of the cutting operation pieces to be threaded usually have necks or recesses whose diameter is smaller than the minor diameter of an external thread (Fig. 377*a*) and greater than the major diameter of an internal thread (Fig. 377*b*).

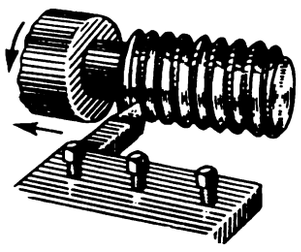


Fig. 373

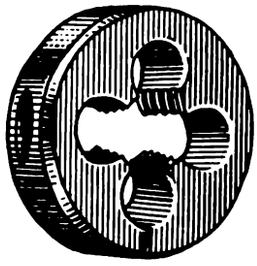


Fig. 374

Dimensions of necks and recesses are stipulated by the USSR Standard.

If an external thread is cut with a die, no neck is made. In this case the thread terminates in a section of incomplete profile due to the design of the die. These are called vanish, or washout, threads. The same occurs in threading a blind hole with a tap. Lengths l and l_1 of external and internal vanish threads are shown in Fig. 378*a* and *b*, respectively, the corresponding profiles being drawn to a larger scale (in both cases 5/1).

To facilitate the screwing of a nut on a bolt or of a pin in a threaded hole the ends of screws, bolts and pins are provided with chamfers (of taper, or sometimes spherical shape). Threaded holes are also chamfered.

A new USSR standard on thread accuracy establishes the following three classes: high, medium and low accuracy ones, and stipulates the designation of thread accuracy in drawings.

Adopted in the USSR for metric threads for the instrument-making industries, is the CMEA (Council of Mutual Economic Aid) standard.

Fig. 375

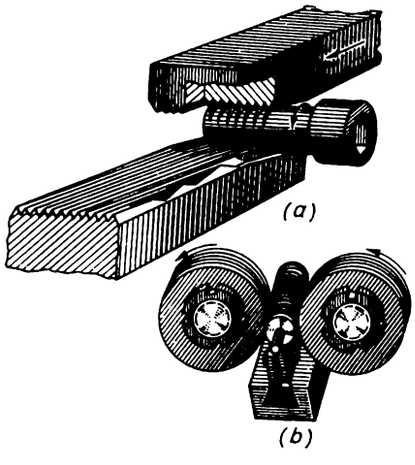


Fig. 376

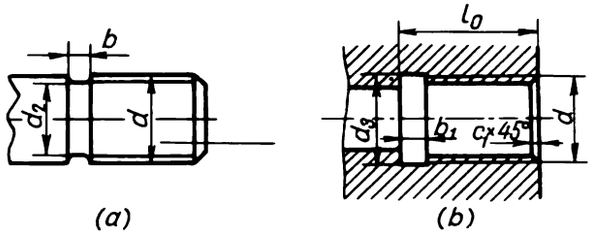


Fig. 377

On the basis of a convention, this standard has been adopted in all the CMEA member countries: Bulgaria, Czechoslovakia, Cuba, the GDR, Hungary, Mongolia, Romania and the USSR. In the USSR, the diameters and pitches of this thread can be used in other branches of industry if there is sufficient justification.

According to the CMEA standard, metric thread should be designated by the letter "*M*" followed by the values of the nominal diameter *d* and the pitch *p*, expressed in millimetres and separated by the sign "×", for example, *M*15× 0.75. For left-hand thread, the letters "*LH*" should follow the designation, for example, *M*15×0.75 *LH*.

In addition to *M*, *d* and *p*, the lead in mm is also indicated for multiple-start thread. The lead is specified after the "×" sign and is followed by parentheses containing the letter "*p*" and the pitch value in mm. Thus, *M*15×2.25 (*p* 0.75) is the designation for a three-start thread with a pitch of 0.75 mm and a lead of 2.25 mm.

The nominal diameters (sizes) of the threads are divided into two series. The sizes of the first series are preferred.

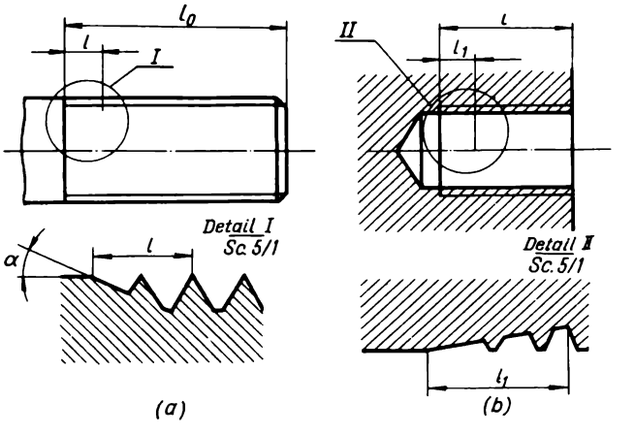


Fig. 378

4. THREAD DESIGNATIONS. SPECIFYING THREADS ON DRAWINGS

Standards that establish the parameters of the various types of threads also cover their designation. Such designations usually consist of letters indicating the type of thread, and the thread size. If the same size of thread may have different pitches or classes of accuracy, then these items should also be indicated in the designation.

(1) Metric thread with a major (nominal) diameter of 24 mm cut with coarse pitch to the 2nd-class accuracy, has the designation: *M24 Cl. 2*. The pitch is not indicated because, accord-

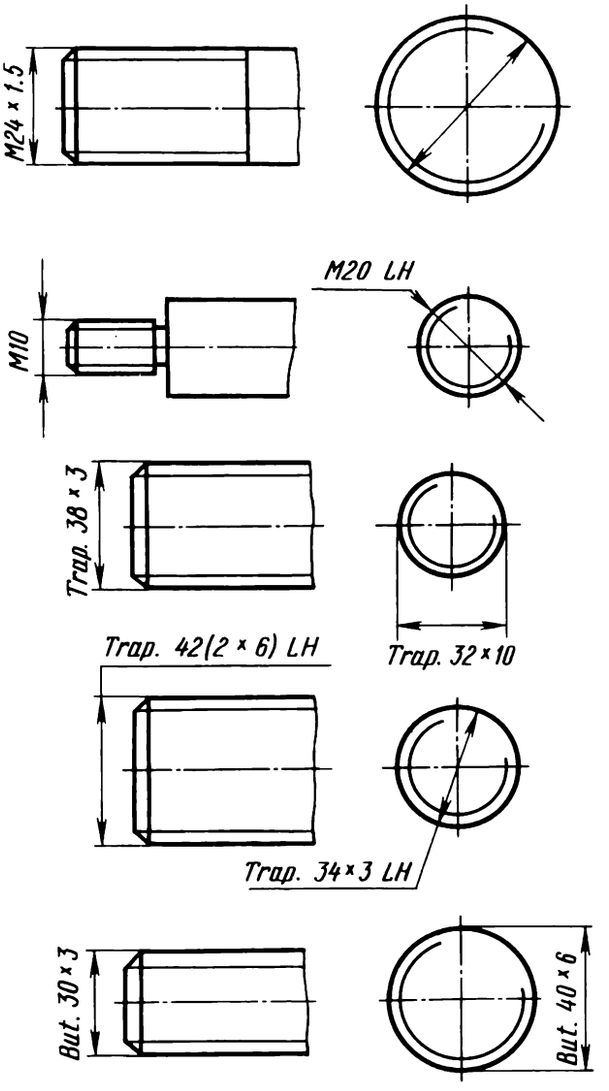


Fig. 379

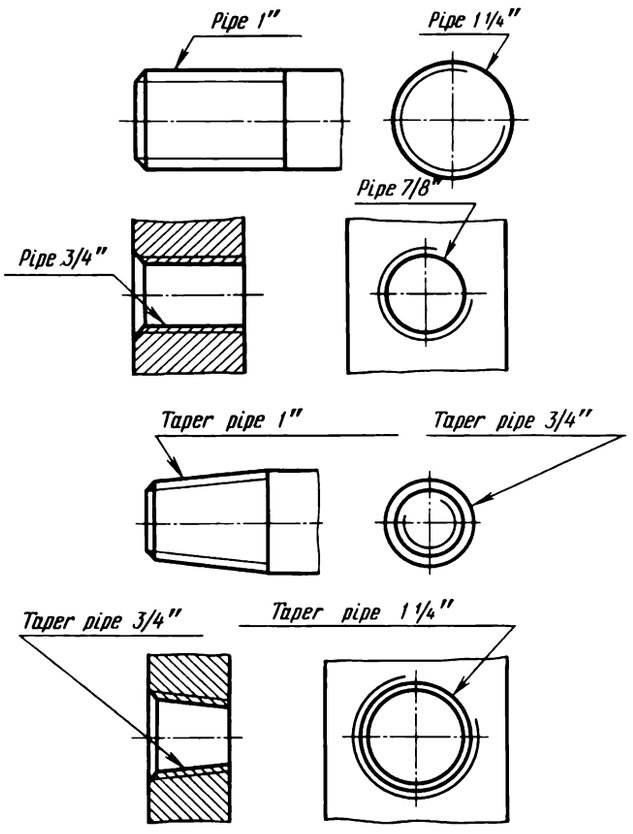


Fig. 380

ing to the USSR standard, the thread of each standard major (nominal) diameter has a single coarse pitch of its own.

It is necessary, however, to indicate the pitch of fine-pitch metric threads because the threads of the same major (nominal) diameter may have different pitches. For example, a metric thread with a major diameter of 16 mm and a fine pitch equal to 0.5 mm, manufactured to the 1st-class accuracy, is designated as *M16×0.5 Cl. 1.*

Production drawings also specify the tolerance zone of the thread diameter. This designation consists of a number and one or two letters, which indicate the main deviation (see Chap. 7). This designation follows the basic thread designation. For instance, a metric coarse-pitch thread for a bolt may be designated as *M16-6g;* if it has a fine pitch, it may be *M16×1-6g.* Such designations are for screws, studs or bolts. If the thread is in a nut, the designation may be *M16-6H* for a coarse-pitch thread, of *M16× 0.5-6H* for one of a finer pitch.

The tolerance zone of the thread diameter and its class of accuracy can be omitted on train-

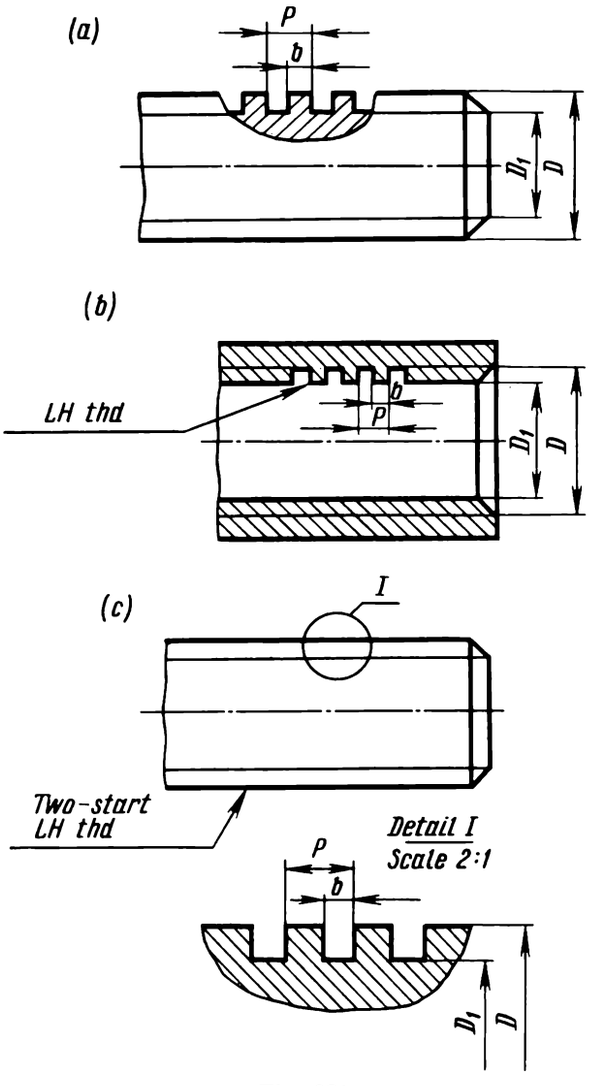


Fig. 381

ing drawings. For example, a coarse-pitch metric thread may be *M16*, one with a fine pitch, *M16×1*, and if it is a left-hand thread, *M20 LH*, adding the abbreviation for left-hand.

Examples of designations for metric threads on drawings are given in Fig. 379.

(2) The designation for trapezoidal thread, *Trap. 38×3 Cl. 1*, specifies the major diameter (38 mm), the pitch (3 mm) and the required class of accuracy (Cl. 1).

The number of starts of multiple-start thread and its pitch are given in the designation in the form of a product. For example, a special trapezoidal three-start left-hand thread with a major diameter of 80 mm and a pitch of 12 mm is designated as: *Trap. 80×(3×12) LH.*

(3) Single-start buttress thread with a major diameter of 60 mm and a pitch of 10 mm should have the designation: *Butt. 60×10.*

Examples of the designations of trapezoidal and buttress threads on drawings are illustrated in Fig. 379.

(4) The designation of taper and cylindrical pipe threads, indicating the thread size by the conventional size of the pipe on which it is cut, is shown in Fig. 380.

Thread with a non-standard profile is represented in a drawing by one of the ways shown in Fig. 381, indicating all the dimensions required for making the thread (form of the profile, major and minor diameters, pitch, etc.). Additional information (number of starts, hand of thread, etc.) is placed on a leader in the form of a note, adding the word "thread" or the abbreviation "thd".

5. BOLTED JOINTS

A bolted joint, as a rule, consists of three parts: a bolt, a nut, and a washer (Fig. 382*a*). The bolt consists of a chamfered head (in most cases a hexahedral prism), and a shank with a triangular thread (Fig. 382*b*).

In drawing bolts use the dimensions tabulated in the appropriate standard.

Boltheads are designed in different ways. Shown in Fig. 383 are bolts with a reduced hexagonal head specified in the USSR Standard. They are available in three modifications: 1 — without holes; 2 — with a cotter-pin hole on the threaded portion of the shank; 3 — with two through holes in the head intended for wire to tie a group of bolts and thus prevent loosening from vibrations and shocks.

All dimensions necessary for manufacturing

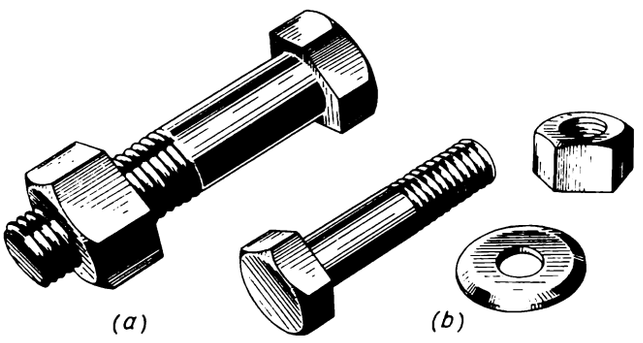


Fig. 382

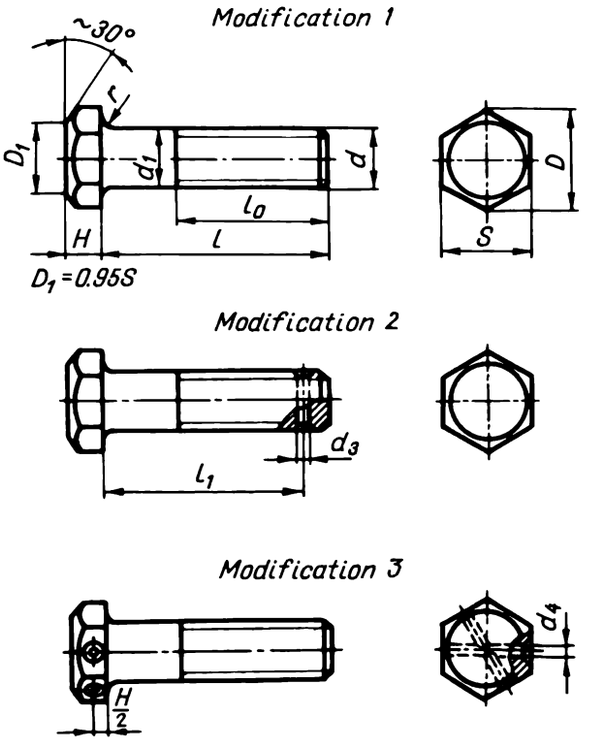


Fig. 383

the above mentioned bolts are given in Table 11 taken from the USSR Standard.

Suppose it is required to draw a bolt with a hexagonal head and a metric coarse thread M14, then all the necessary dimensions are to be taken from Table 11 or from the corresponding standard, namely:

bolt shank length $l=50$ mm (l is chosen depending on the thickness of the parts to be fastened); length of the threaded portion $l_0=34$ mm; size of the bolthead across corners, or diameter of circumscribed circle $D=25.4$ mm; height of the bolthead $H=9$ mm; chamfer angle $\alpha=30°$; distance across flats of the bolthead $S=22$ mm; thread pitch 2 mm.

The minor diameter of the thread is taken from the appropriate standard for metric threads ($d_1=11.835$ mm).

Draw (first in thin continuous lines) the outlines of the bolt with the bolthead but without chamfers (Fig. 384). Then calculate the diameter of the chamfer circle ($D_1=0.95\ S$) and construct, see the figure, the lines of intersection of the chamfer surface with six faces of the bolthead.

The conic sections thus obtained are hyper-

Table 11

Standard Bolts with Hexagon Heads Specified in the USSR Standard

(Dimensions in mm)

Nominal thread diameter, d		6	8	10	12	(14)	16	(18)	20	(22)	24	(27)	30	(36)	42	48
Thread pitch	coarse	1	1.25	1.5	1.75	2	2	2.5	2.5	2.5	3	3	3.5	4	4.5	5
	fine	—	1	1.25	1.25	1.5	1.5	1.5	1.5	1.5	2	2	2	3	3	3
Shank diameter (nominal), d_1		6	8	10	12	14	16	18	20	22	24	27	30	36	42	48
Distance across flats of the bolthead, S		10	14	17	19	22	24	27	30	32	36	41	46	55	65	75
Height of the bolthead, H		4	5.5	7	8	9	10	12	13	14	15	17	19	23	26	30
Size of the bolthead across corners, or diameter of circumscribed circle, D		11.5	16.2	19.6	21.9	25.4	27.7	31.2	34.6	36.9	41.6	47.3	53.1	63.5	75.0	86.5
Fillet radius, r (approx.)		0.5		0.6	0.8		1.0				1.5			2.0		
Shank hole diameter, d_3		2			3		4			5			6	8.0		
Bolthead hole diameter, d_4		0.8	2	2.5	3	3.5	4							5		

Bolt length, l	Nominal thread diameter, d																											
	6		8		10		12		(14)		16		(18)		20		(22)		24		(27)		(30)		36		42	
	Length of the threaded portion l_0 (vanish threads included) and distance l_1 between the bearing surface of the bolthead and the axis of the shank hole (designated by X are bolts with a shank threaded throughout its length)																											
	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0	l_1	l_0
50	46	18	46	22	46	26	45	30	45	34	44	38	44	42	44	X	43	X	43	X	—	—	—	—	—	—	—	—
55	51	18	51	22	51	26	50	30	50	34	49	38	49	42	49	46	48	X	48	X	—	—	—	—	—	—	—	—
60	56	18	56	22	56	26	55	30	55	34	54	38	54	42	54	46	53	50	53	X	52	X	51	X	—	—	—	—
65	61	18	61	22	61	26	60	30	60	34	59	38	59	42	59	46	58	50	58	54	57	X	56	X	—	—	—	—
70	66	18	66	22	66	26	65	30	65	34	64	38	64	42	64	46	63	50	63	54	62	60	61	X	—	—	—	—
75	71	18	71	22	71	26	70	30	70	34	69	38	69	42	69	46	68	50	68	54	67	60	66	66	65	X	—	—
80	—	—	76	22	76	26	75	30	75	34	74	38	74	42	74	46	73	50	73	54	72	60	71	66	70	X	68	X
(85)	—	—	81	22	81	26	80	30	80	34	79	38	79	42	79	46	78	50	78	54	77	60	76	66	75	X	73	X

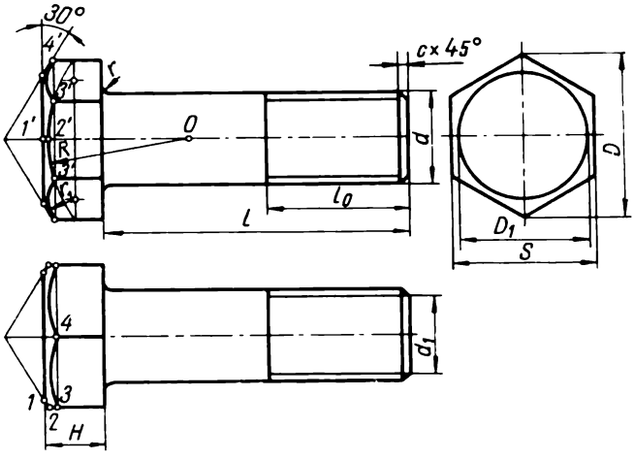


Fig. 384

bolas, but for the sake of simplicity they are substituted by circular arcs. The radii of these arcs are determined by a method known from geometrical drawing, in which the centre and radius of an arc are determined from three given points through which the required arc passes (Fig. 384). To this end, first determine the vertical projection of the generatrix of the chamfer cone by drawing the extreme elements through the ends of the vertical projection of D_1 at an angle of 30°. The required arcs will pass through the points of intersection of the extreme generatrices and the edges of the hexahedral prism (for instance, through points *3* and *4* in the figure). Each face contains two such points. The third point is found in the following way: determine the horizontal projection of the point of intersection of the extreme generatrix of the chamfer cone and the side face, point *2*, which is then projected on the plane *V* to obtain point *2'*. From the determined point *O* as a centre draw the required arc of radius *R* which will pass through points *3'*, $3'_1$, and *2'*.

The nut and washer are also drawn using the dimensions in the appropriate tables. Shown in Fig. 385 are nuts with one and two chamfers, respectively, while Fig. 386 illustrates two types of washers. The lines of intersection of the taper chamfer with the nut faces are drawn in the same way as in the bolthead.

Also used to a considerable extent are hexagonal nuts with a reduced distance between the flats, called light series nuts. Other available types are thin nuts, thick nuts and extra-thick nuts.

Standard wing nuts, with lugs, are used when they are to be tightened or loosened by hand without applying a wrench.

A standard-accuracy hexagonal nut, modification 1 (see Fig. 385) can be specified on a drawing by the designation:

Nut M24.4 USSR Std.

A wing nut of the same size has the designation:

Wing nut M24.4 USSR Std.

The most widely applied type of washer, available in two modifications (Fig. 386), is manufactured in the USSR to a standard which lists the dimensions and parameters, and indicates the designation.

The designation of a washer includes the diameter of the fastener (bolt, screw or stud) on which it is to be installed. For example, a washer, modification 1 with no coating, intended for a fastener with a diameter of 24 mm is designated as:

Washer 24 USSR Std.

The same size of washer, modification 2, has the designation:

Washer 2-24 USSR Std.

The parts to be joined must be drilled to a diameter somewhat larger than that of the bolt, thus providing an allowance to ensure a free fit. All hole clearances are standardized. For one and the same bolt, diameter clearances vary,

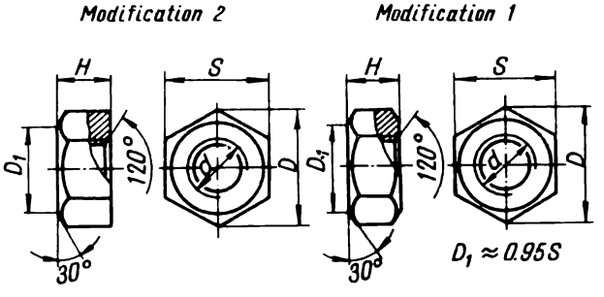


Fig. 385

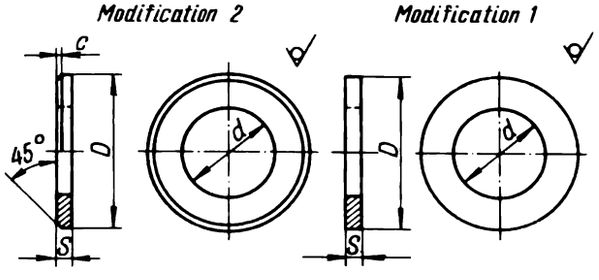
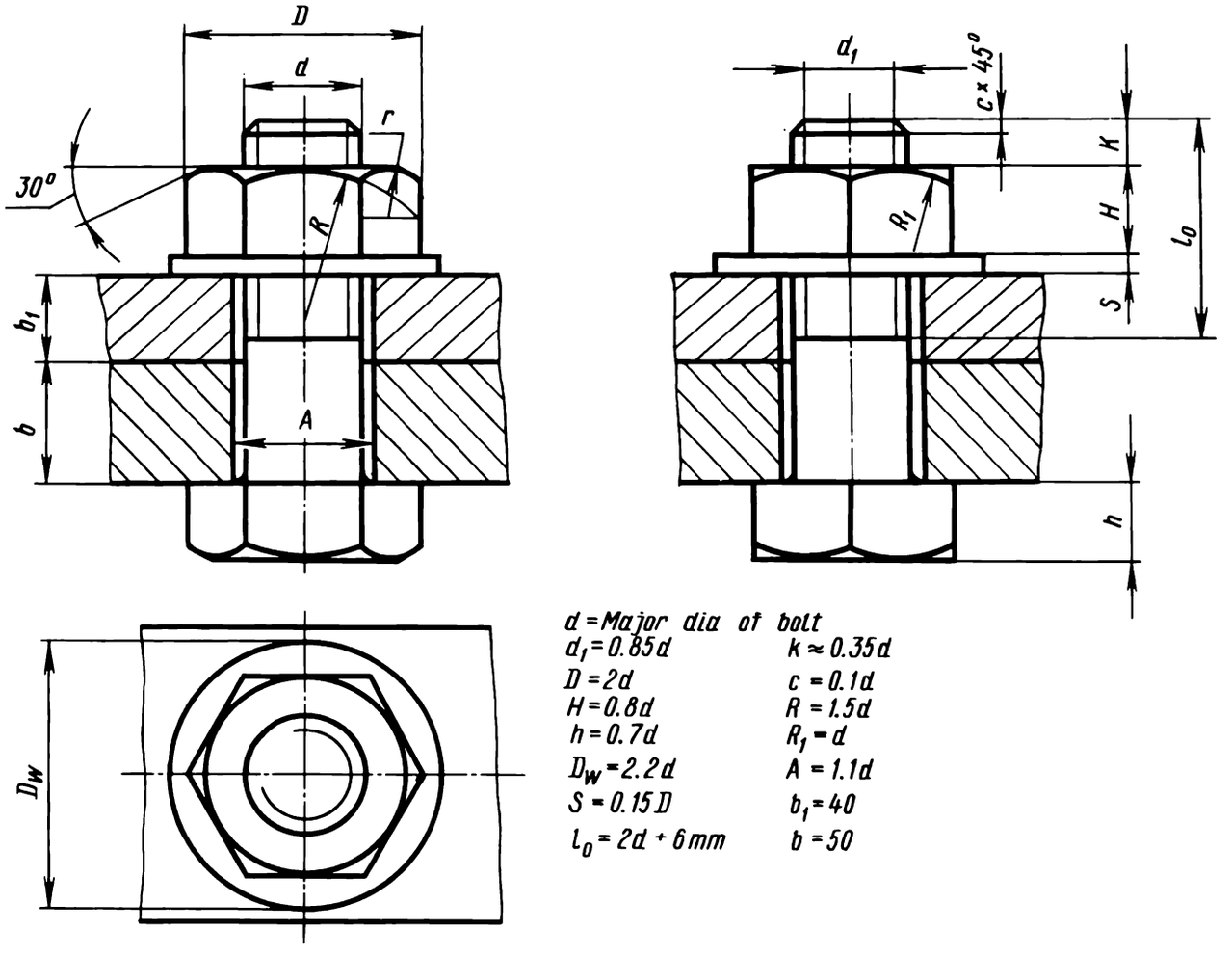


Fig. 386



d = Major dia of bolt

$d_1 = 0.85d$	$k \approx 0.35d$
$D = 2d$	$c = 0.1d$
$H = 0.8d$	$R = 1.5d$
$h = 0.7d$	$R_1 = d$
$D_W = 2.2d$	$A = 1.1d$
$S = 0.15D$	$b_1 = 40$
$l_0 = 2d + 6mm$	$b = 50$

Fig. 387

depending on the accuracy of assembly. To save time in making assembly drawings the hole diameter may be taken as equal to $1.1d$, the true diameter of holes being specified in detail drawings. Illustrated in Fig. 387 is a simplified method of drawing bolts. Conventional ratios between dimensions are used; chamfers and fillets are not shown. All the dimensions of the bolt, hexagonal head and washer noted in Fig. 387 are based on the major diameter of the thread. The length of a bolt (or a stud) usually depends on the thickness of the pieces to be held together, and also on the type of nut (say, hexagonal, castellated, slotted, etc.). The length of the bolt shank is determined as the sum of the thickness of the pieces to be joined, the height of the nut, the thickness of the washer (if any) and the minimum protrusion from the nut, which depends on the thread pitch and approximately equals $0.3d$.

Compare the length thus obtained with those specified in the USSR Standard and choose the one closest to the calculated value.

6. STUDDED JOINTS

The stud is a cylindrical rod with threads on both ends (see Fig. 388).

There are two modifications of studs: with a neck (Type *B*), and without one (Type *A*, see Fig. 389).

Their dimensions are given in the appropriate standard. With one of its ends l_1 (Fig. 390*c*), the stud is screwed into a blind threaded hole in part *A*. Part *B* is provided with a hole drilled

to a diameter somewhat larger than the diameter of the stud. On the other end of the stud a nut is screwed under which a washer is placed.

The stud is used where there is no place for the bolthead, or when one of the pieces being joined is too thick to use the ordinary headed bolt. The length l_1 should be approximately equal to 1 to 1.35 thread diameters. With stronger materials it may be less. According to the Standard the following values of l_1 are recommended:

(a) for screwing a steel stud in a steel or duralumin part, l_1 should be equal to (0.8 to 1)d;

(b) for screwing a steel stud in a gray iron or bronze casting, l_1=(1.3 to 1.4)d;

(c) for screwing a steel stud in an aluminium part subject to the action of variable forces, l_1=(2 to 2.5)d, where d is the major diameter of the stud thread.

Steps in making a threaded hole for a stud, and a studded joint are shown in Fig. 390. Seen in the figure are: (a) a drill and a blind

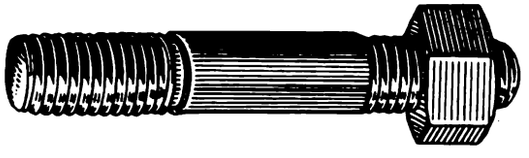


Fig. 388

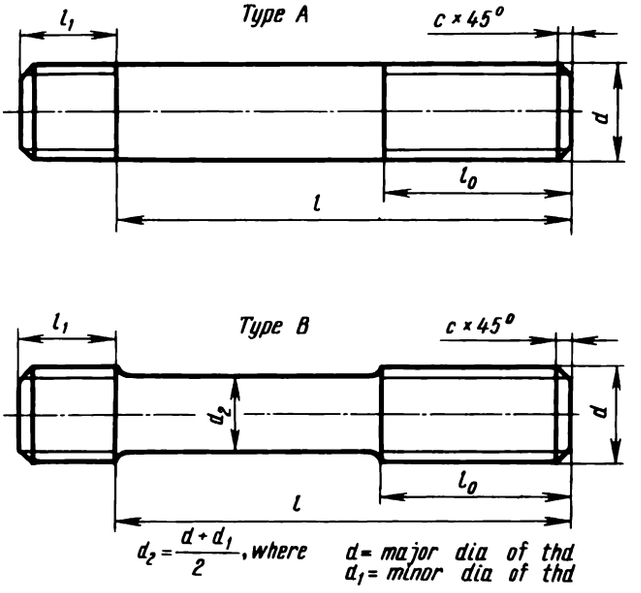


Fig. 389

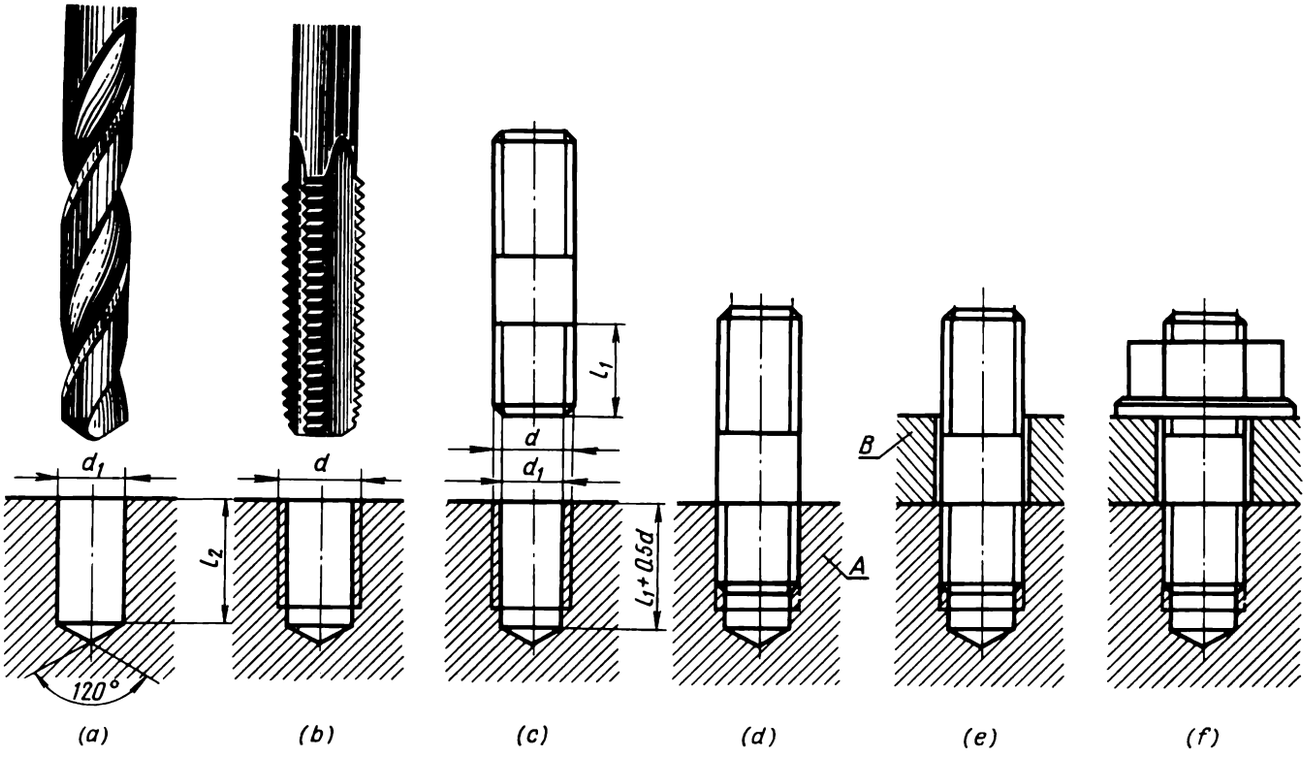


Fig. 390

hole of diameter d_1 drilled in part *A* with a cone at the bottom at an angle of 120°; the hole depth l_2 is taken to be equal to $l_1+0.5d$; (b) a tap and a threaded hole; (c) a stud and a threaded hole; (d) a stud screwed home; (e) the screwed stud with part *B* to be joined; (f) the stud with a washer and a nut screwed on.

In representing studded joints on assembly drawings the dimensions may be given in conventional ratios as for bolted joints.

7. SCREW FASTENINGS

As distinct from the bolt, the screw is driven into a threaded hole in one of the two pieces to be joined (there is no nut in this case). Presented in Figs. 391 and 392 are some types of standard screws and their use.

It should be remembered that the thread in the screw hole is represented on a sectional view in the same manner as in a studded joint. The line denoting the end of the threaded portion of a screw is higher than the demarcation line between the two adjacent parts, which makes it possible to tighten the screw if necessary.

Depending on their purpose screws are manufactured with various styles of heads and points. The main purpose of the majority of screws is to fix the position of one part with respect to the other. Standard screws are illustrated in Fig. 391.

The set screw with a flat point (Fig. 391) is used as a fastener.

The slotted sunk-head screw (Fig. 391) is used where the screwhead should be flush with the surface.

Screws with slotted flat-fillister heads (Fig. 391) are widely used in engineering.

Wood screws with heads of various shape have cylindrical or taper thread, their upper portion being usually unthreaded. Wood screws are used for fastening wood to wood or metal to wood (see Fig. 392*d*). The thread of wood screws has a sharp triangular profile and a large pitch.

To prevent nuts from working loose due to jerks, vibrations, etc., various locking devices are used, such as nut locking devices, various types of washers, cotter pins, etc. (see Fig. 393), their dimensions and shapes being standardized.

Shown in Fig. 393*a* and *b* are *tongued lock*

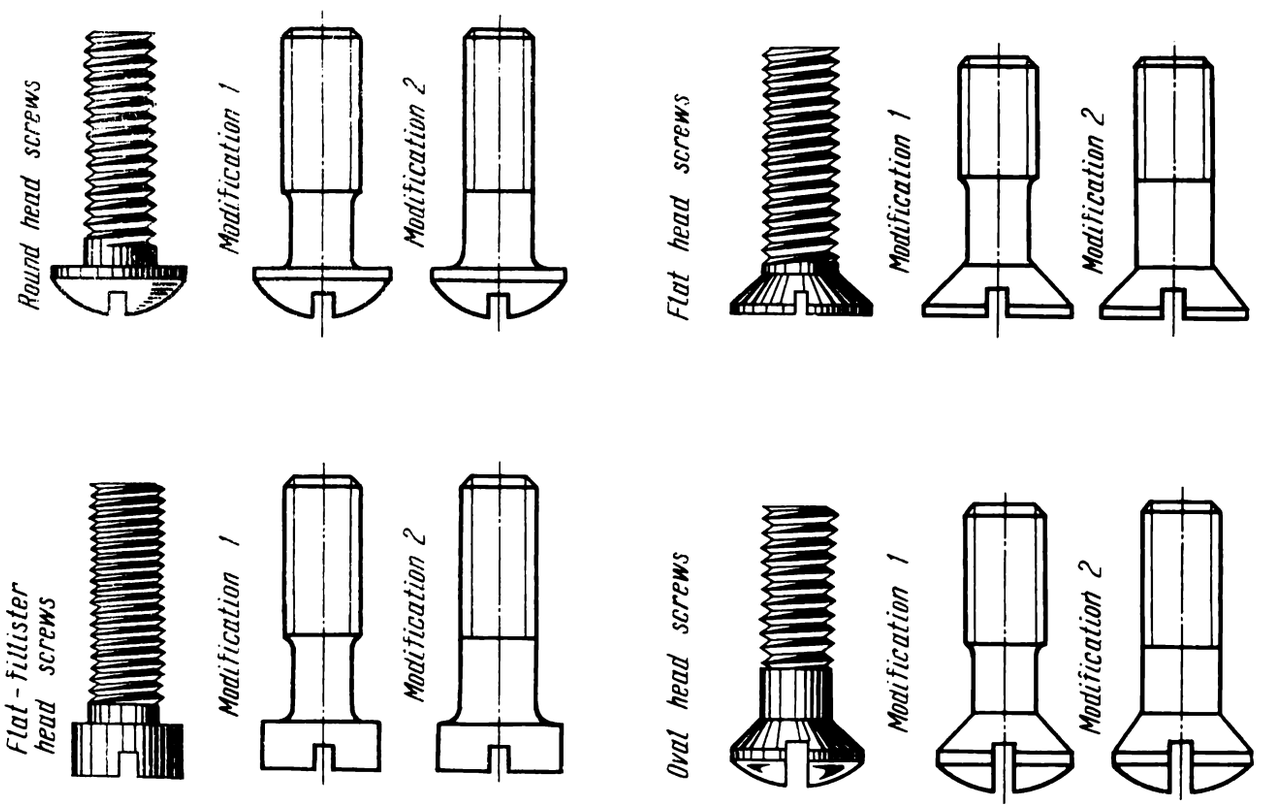


Fig. 391

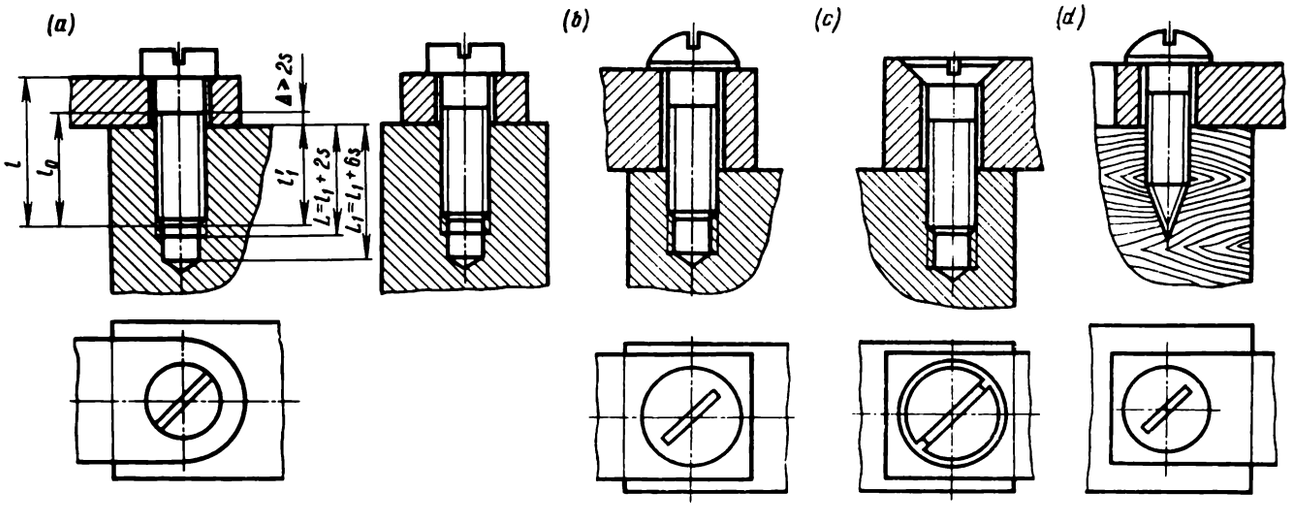


Fig. 392

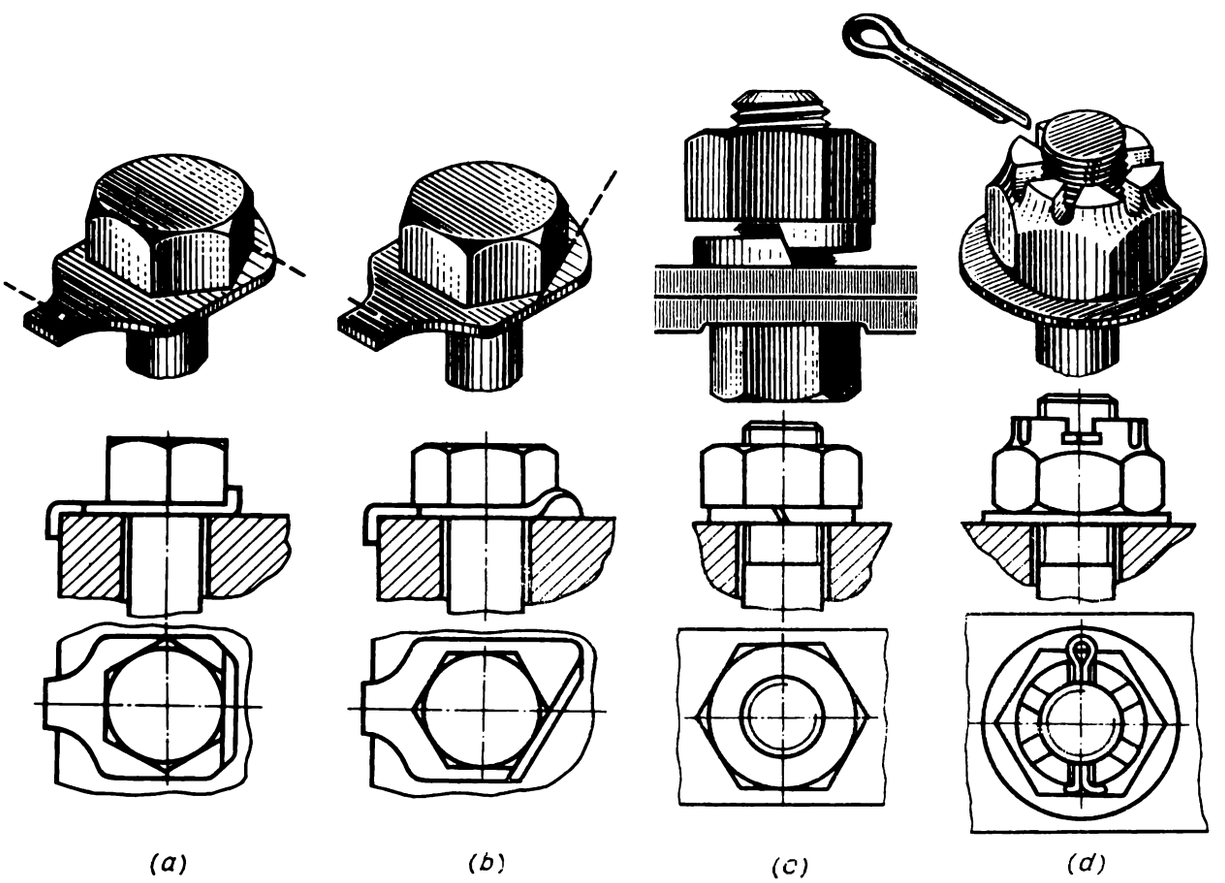


Fig. 393

washers whose tongues are bent on screwing in the bolts.

Spring washers are made of spring steel. They represent one turn of a coil spring with a square section and sharp edges which prevent the nut from unscrewing (Fig. 393*c*).

Figure 393*d* is an example of locking a slotted nut with a *cotter pin* made of steel wire of semicircular section. After screwing on the nut a radial hole is drilled in the stud to a diameter slightly larger than that of the pin. On inserting the pin its ends are bent.

8. SIMPLIFIED AND CONVENTIONAL REPRESENTATIONS OF SCREW JOINTS

The pertinent USSR standard covers simplified and conventional representations of screw fastenings on assembly drawings.

Simplified representations of certain screw joints that have been dealt with previously are shown in Fig. 394*a*. In such drawings, the thread is shown along the full length of the threaded portion of the fastening. Chamfers, fillet radii and clearances between the shank of the bolt, stud or screw and the hole it passes through are not shown. In views obtained by projection on a plane perpendicular to the thread axis, the thread is shown as a single circle equal to the major diameter (an arc corresponding to the minor diameter is not drawn). Washers used in the joint are not shown in these views.

The proportions of the elements of screw fastenings should be maintained in simplified drawings of screw joints. In teaching practice, for example, the following proportions, based on the shank diameter *d*, are widely used in drawings of bolt heads, nuts and washers (Fig. 394*a*):

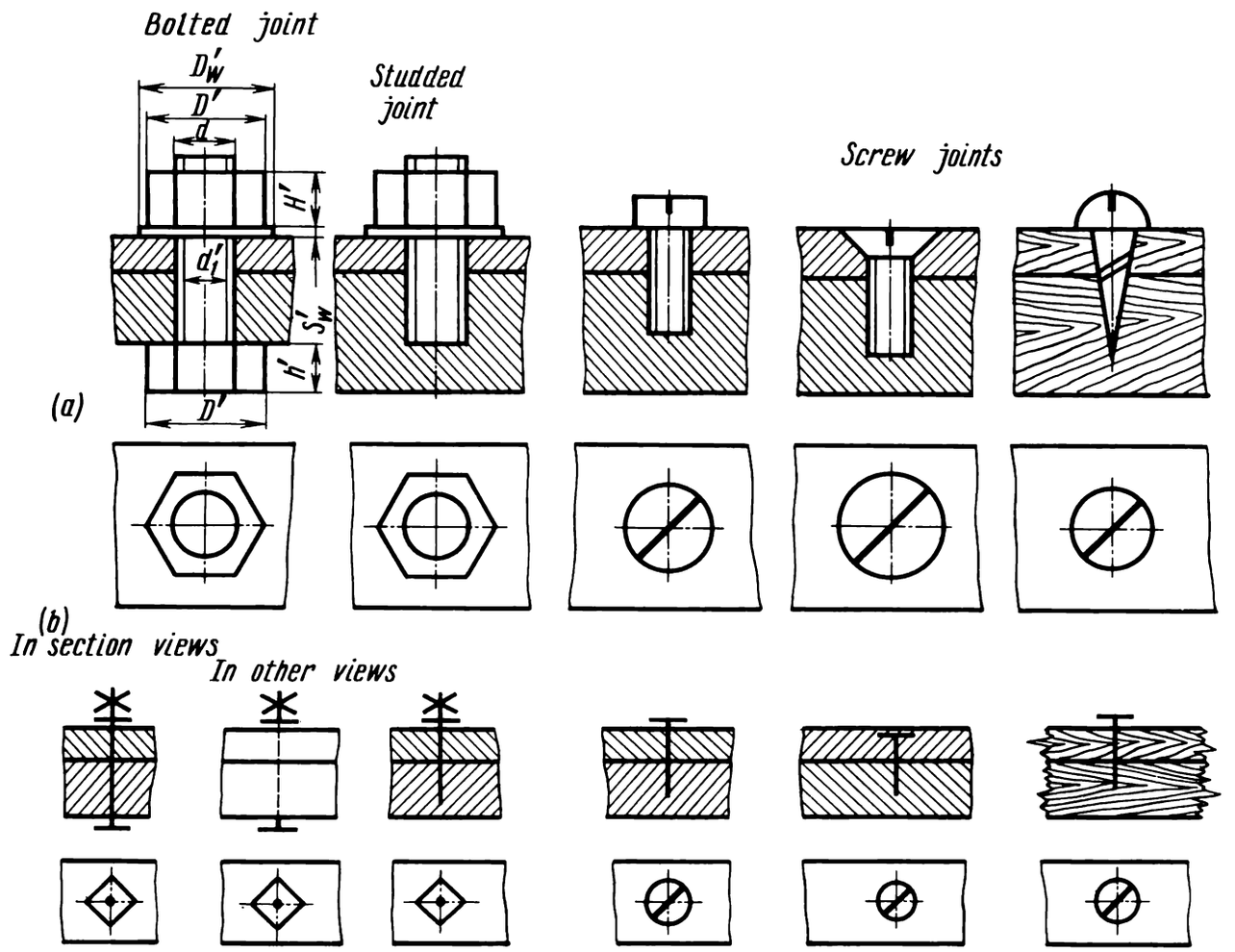


Fig. 394

$d_1' = 0.85d$, $D' = 2d$, $h' = 0.7d$, $H' = 0.8d$, $D_W' = 2.2d$ and $S_W' = 0.15d$.

Slots in the heads of machine and wood screws are depicted by a single heavy continuous line.

Conventional representations (Fig. 394*b*) are used when the shank diameter of the fastenings in the drawing is equal to or less than 2 mm. The size of the conventional representation on the drawing and the way it is made must give a complete idea of the joint and its components.

The USSR standard provides for the use of these conventions both in the regular views and in sections, as is illustrated in Fig. 394*b* for bolt, stud and screw joints.

9. STANDARD THREADED FASTENINGS AND THEIR DESIGNATION

Threaded fastening components (bolts, screws, studs and nuts) are extensively employed in separable joints. A great many standard types of these fastenings are available. They are all manufactured to standards which establish definite requirements concerning the materials of which the fastenings are to be made, coatings, finish and other manufacturing specifications.

In geometrical features, dimensions, thread, dimensional tolerances and tolerances of form, and surface roughness, each type of fastening should comply with the requirements established by the pertinent dimensional standard. In countries which use the metric system, the overwhelming majority of threaded fastenings are made with metric threads. Mainly coarse-pitch threads are used; fine pitches are much less frequently used.

The sizes of vanish (wash-out) threads, incompletely cut or rolled portions of the thread, and chamfers at the ends of threads on bolts, screws or studs are also covered by the pertinent standards.

Depending upon the required *mechanical properties* and *material* of which it is made, a fastening belongs to a *definite strength class* or *group*. A series of such classes and groups is established in the USSR by the standard. Some of them are listed in Table 12.

Specified for each strength class and group are the requirements for the mechanical strength of fastenings and the grades of materials of which they can be made.

The strength class of bolts, screws and studs

Table 12

Strength Classes and Groups of Threaded Fastenings (USSR Std.)

Threaded fastening	Material	
	Carbon and alloy steels	Nonferrous alloys
	Strength classes	Groups
Bolts, screws and studs	3.6, 4.6, 4.8, 5.6, 5.8, 6.6, 6.8, 6.9	31, 32, 33, 34, 35, 36
Nuts	4, 5, 6, 8	

is designated by a two-digit number of which each digit specifies definite parameters of the strength of the material of which the fastenings are to be made.

The strength class of nuts is designated by a single digit which indicates the state of the material when the test load is applied.

Protective coatings are employed to prevent corrosion of fastenings. The pertinent USSR standard establishes the following designations for coatings: *00* — no coating; *01* — zinc chromatized; *02* — cadmium chromatized; *03* — multicoat (copper and nickel); *04* — multicoat (copper, nickel and chromium); *05* — oxidized; *06* — phosphatized with oiling; *07* — tinned; *08* — copper-coated; *09* — zinc-coated; *10* — oxide anodized with chromatizing; *11* — passivated; and *12* — silver-coated.

The *designation* of any standard fastening component should specify:

(1) shape and basic dimensions of the fastening and its elements, which are determined by the corresponding dimensional standard;

(2) strength class or group of the fastening, specifying the mechanical properties of its material;

(3) designation of the coating which protects the fastening against corrosion.

The elements in the following designation of a fastening:

Bolt 2 M16×1.56g×75. 68.09 USSR Std., specify:

Bolt — name of the fastening;

2 — modification *2;*

M16 — type and size of the thread;

1.5 — pitch of the fine-pitch thread;

6g — thread accuracy;

75 — length of the bolt;

68 — strength class 6.8, indicating that the bolt is to be made of steel with definite mechanical properties;

09 — zinc coating;

USSR Std — a dimensional standard indicating that the bolt has a hexagonal head and is of standard accuracy.

If the bolt designated above had to be made of some nonferrous alloy rather than steel, the corresponding group would have been specified in place of the strength class (see Table 12).

The USSR Standard stipulates that modification 1, thread accuracies 8g and 7H, and coating 00 (i.e., no coating) are not to be specified in the designation. If we also take into consideration the fact that the pitch of coarse thread is not indicated, it is clear that in many cases the designation of a threaded fastening may be simpler than the example given above.

It should be noted that without special knowledge of the subject it is impossible to properly assign the strength class of a fastening Consequently, in the drawing course, we can arbitrarily take the lowest strength classes: *3.6* for all bolts, screws and studs, and *4* for all nuts.

In order to simplify the designations of threaded fastenings, we may apply items without any coating, with coarse-pitch thread, and having an accuracy of *8g* or *7H*. Given below are designations for use in the drawing course; it is assumed that:

1. All the fastenings in the examples have *M24* coarse-pitch thread made to an accuracy of *8g* or *7H*.
2. Bolts, screws and studs are of length $l=$ 80 mm and strength class *3.6*.
3. Nuts are of strength class *4*.
4. None of the fastenings has a protective coating.

The designation of a bolt of standard accuracy with a hexagonal head, modification *1* (see Fig. 383) is:

Bolt M24×80.36 USSR Std.

The bolt of the same size, but of modification *2* is designated as:

Bolt 2 M24×80.36 USSR Std.

10. PIPE CONNECTIONS

Pipes for water supply lines, central heating and gas lines are connected by means of specially designed parts called fitting pieces, or fittings.

Fittings are available in various shapes: elbow pieces, tee-pieces, cross pipes, and couplings; some of them are illustrated in Fig. 395. Shown in Fig. 396 are pipes connected by means of a tee-piece.

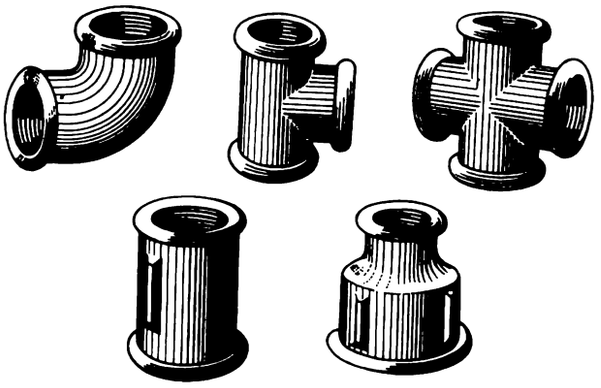


Fig. 395

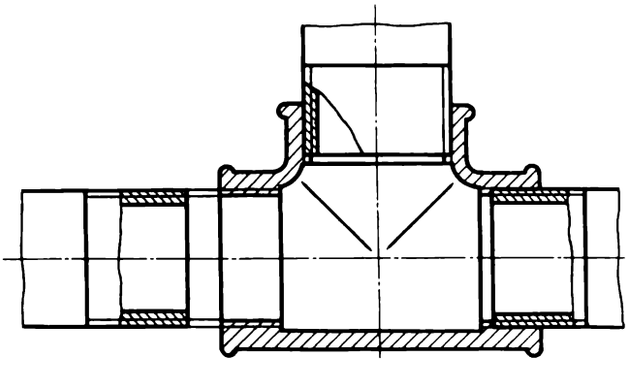


Fig. 396

Conventional representation of pipe thread connections is similar to that for a bolted joint (see Fig. 396).

In drawing a pipe connection the pipes should be shown as in Fig. 396, i.e., screwed in only part way, which permits adjusting the pipe

Table 13

From the USSR Standard

(Dimensions in mm)

D_{conv}	Thread designation	Pipe					Tee-piece			
		l_0	c	l	c_1	L	d_1	S	b	h
25	Pipe 1″	11		15		38	34.0	3.3		2.5
40	Pipe 1 1/2″	15	2.5	19	1.5	50	48.5	4.0	4	3.0
50	Pipe 2″	17		21		58	60.5	4.5	5	3.5

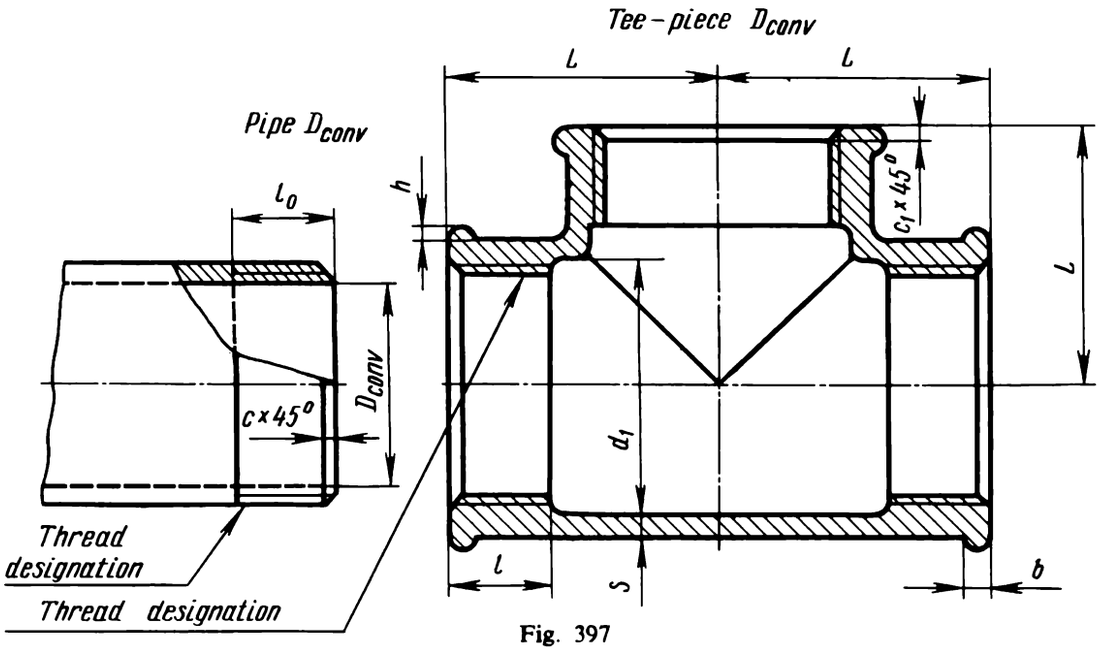


Fig. 397

length between fittings; all the necessary dimensions should be taken from the tables in the corresponding standards.

For example, in a tee-piece connection of a pipe with a conventional internal diameter $D_{conv}=25.4$ mm (see Fig. 397) the male thread of the pipe of diameter $d=33.25$ mm will be conventionally designated as Pipe 1″ (see Table 13). All the other dimensions of the tee-piece are taken from the same table.

Questions

1. What kinds of threaded products are used in mechanical engineering?
2. How is a helix constructed on a right circular cylinder?
3. Give the definitions of the direction and pitch of the helix.
4. What thread profiles do you know?
5. What is a multi-thread screw and what is the difference between its pitch and lead?
6. What types of standard threads are used in mechanical engineering?
7. How are metric threads with coarse and fine pitches designated?
8. What are the characteristic features of a pipe thread, and how is it designated?
9. What are the tools and methods of thread cutting employed in modern mechanical engineering?
10. What are vanish, or washout, threads?
11. What is the difference between drawing a bolt (or stud) to the dimensions specified in the corresponding standard and using conventional ratios? Where are these methods used?
12. Give the definitions of a bolt and a screw.
13. Where are screws of various types used?
14. What are the methods of preventing a nut from working loose due to vibrations, shocks, etc.?
15. What are the symbols and designations for pipe, taper, and trapezoidal threads?

Exercise 63

Construct a cylindrical helix, given: the altitude of the cylinder $h=80$ mm, its base diameter $D=50$ mm, helix pitch $p=40$ mm, direction — right-hand.

Exercise 64

Make a drawing of a bolted joint; take the diameter and length of the bolt shank, nut, and washer from Table 11 (see Fig. 398*a*), the rest of the dimensions being determined from the conventional ratios.

Exercise 65

Make a drawing of a studded joint; take the diameter and length of the stud, nut and washer from Table 11 (see Fig. 398*b*), the rest of the

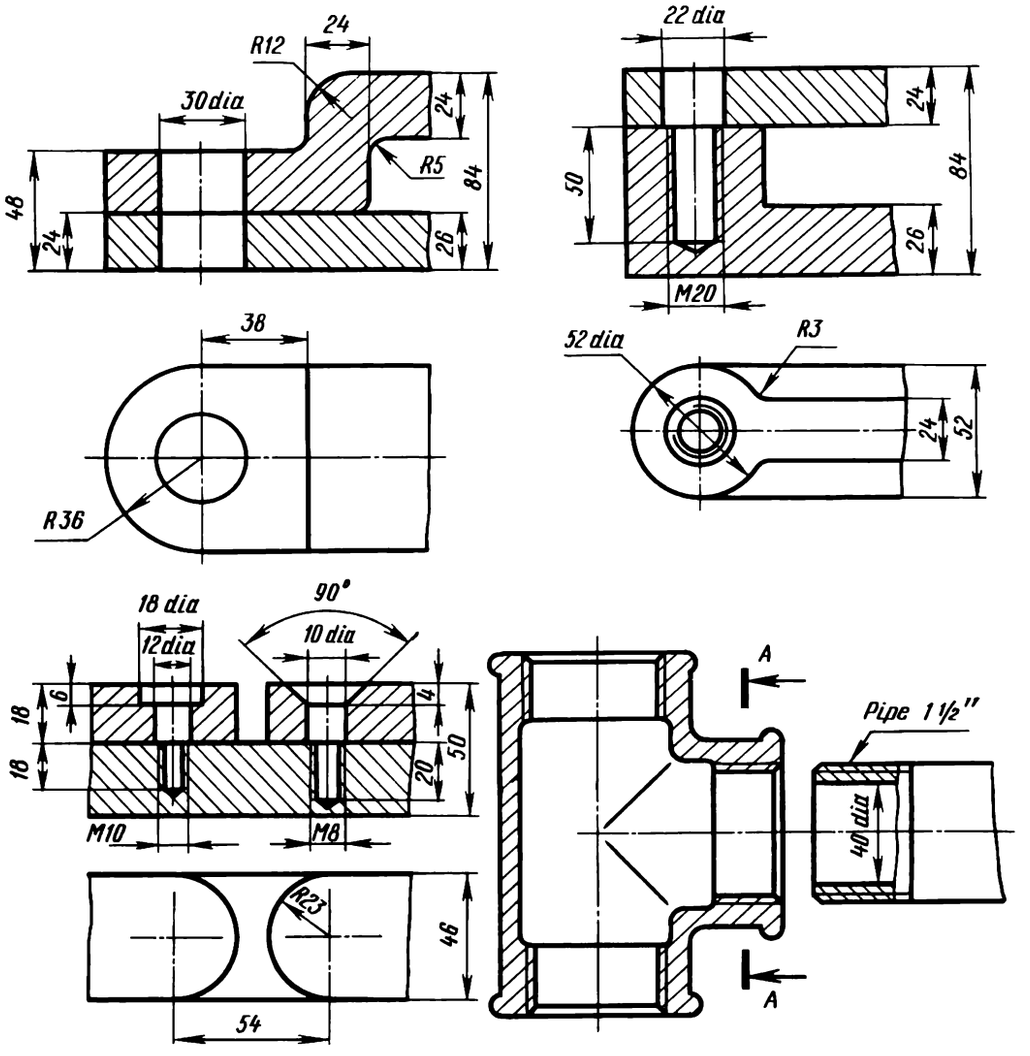


Fig. 398

dimensions being determined from the conventional ratios.

Exercise 66

Make a drawing of a cylindrical-head screw fastening to dimensions chosen from Table 11 (see Fig. 398*c*).

Exercise 67

Make a drawing of a pipe connection by means of a coupling according to the corresponding standard (see Fig. 398*d*).

Note: Give the thread designation; dimensioning is not needed.

CHAPTER 4

SKETCHES AND WORKING DRAWINGS OF MACHINE ELEMENTS

1. TECHNICAL SKETCHING

By a *sketch* we mean a freehand drawing. A sketch differs from a drawing in that all its lines are drawn by hand in as nearly correct proportion as the eye can determine, without taking measurements. After the sketch of a piece is finished the necessary dimension lines should be added. Draw extension lines and arrowheads carefully and see that none are omitted. The dimensions indicated on the sketch must correspond to the actual dimensions of the piece.

It is common practice to make sketches in pencil (soft grades 2M and 3M) on graph paper which facilitates freehand sketching.

In sketching use lines of the types and thicknesses specified for drawings. The views must be large enough to enable the dimensions, conventional symbols and inscriptions to be indicated.

Before making a sketch it is essential to visualize the object, to determine the main view and the number of views, sectional views and revolved sections required to give a clear idea of the piece. It is good practice to establish the constituent geometrical elements of the given piece.

Pay attention to the machined and non-machined surfaces, to gradual transition from one surface to another, to draft and fillets for castings, stampings, and so on.

Various grooves, slots, flats, etc., on machined surfaces should be adequately shown and dimensioned on the sketch.

Inevitable production defects, such as uneven wall thickness, misaligned geometrical axes of concentric circles, out-of-roundness, etc., should by no means be transferred to the sketch.

2. DATUM SURFACES

Dimensioning of sketches and working drawings is based on the requirements of design and the conditions of manufacture and inspection. That is why, prior to dimensioning, it is necessary to choose certain *datum surfaces*, from which the part is to be measured in machining and from which all dimensions are checked.

In mechanical engineering we distinguish between *design datum* and *production datum surfaces.*

Mutual positions of different surfaces of a machine part are specified by linear (sometimes angular) dimensions.

Lines and points of a part drawing with respect to which the designer orients other parts are called *design datum features.*

The *production datum surface* is a machine part surface from which it is most convenient to locate the part for machining and to carry

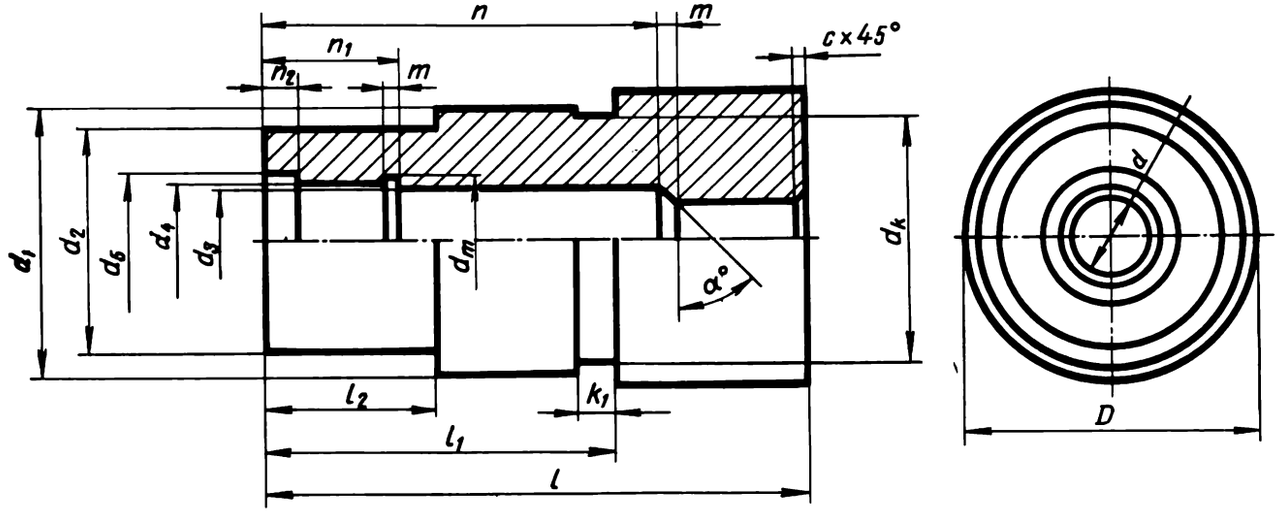


Fig. 399

out measurement during machining. Dimensions assigned from design, datum features often do not coincide with those taken from production datum surfaces. Hence, it is very difficult to meet the requirements of design and production at the same time.

Shown in Fig. 399 is a bush. Let us consider one of the possible ways of dimensioning this part from a production datum surface — the left-hand end face of the bush.

Note that all dimensions specifying the outside surface of the piece are indicated below, and those specifying the inside surface are given above the half-section view. All the dimensions are placed so that it is very easy to make and measure the part.

When machining the outside surface first turn the bush to diameter d_1 over the length l_1, then turn it to diameter d_2 over the length l_2. The neck of width k_1 is made by means of a tool whose cutting edge is equal to k_1 in width. The drawing is dimensioned so as to correspond to the sequence of machining the outside surface of the bush, as well as to facilitate its checking. With the dimensions placed in such a manner there is no need of computation, each dimension corresponding to a certain machining operation.

The inside surface is dimensioned and machined as follows. First drill a through hole of diameter d, then bore it to diameter d_3 over the length n. The angle α corresponds to the point angle of the drill. Then bore the hole to diameter d_4 over n_1, and, finally, to diameter d_5 over n_2. Now make a recess of width m to diameter d_m by means of a cutting tool. The final operation is cutting the piece down to the dimension l and chamfering to $c \times 45°$.

3. DIMENSIONING

All machine parts are made to drawings on which all dimensions should be placed. These are chosen from the series of standard linear dimensions:

... 10, 10.5, 11.5, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 28, 30, 32, 34, 36, 38, 40, 42, 45, 48, 50, 52, 55, 60, 63, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 120, 125, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 240, 250, 260, 280, 300, 320, 340, 360, 380, 400.

For parts with precision finished contacting taper surfaces (for instance, a plug in a cock) the drawing must specify the taper. For this purpose use should be made of Table 14.

Table 14

Standard General-purpose Tapers
(acc. to the USSR Standard)

Taper t	Taper angle 2α	Application
1:50	1° 8′ 45″	Taper pins, ends of slip-on handles
1:15	3° 49′ 6″	Rod-piston connections
1:12	4° 46′ 19″	Tapered mounting sleeves for ball and roller bearings
1:7	8° 10′ 16″	Fitting cock plugs
1:5	11° 25′ 16″	Friction clutch tapers
1:1.207	45°	Packing tapers for light nipple pipe connections
1:0.866	60°	Machine-tool centres
1:0.500	90°	Ends of machined axles and shafts. Valve chamfers
1:0.289	120°	Inside chamfers of threaded holes
		Packing cones
		Throttle valves

Tapers are standardized in mechanical engineering. Tapers in different machine parts vary depending on their functions (see Table 14). Figure 400 illustrates their applications.

According to their type and dimensions tapers fall into two main groups: (1) *metric tapers* (from No. 1 to No. 6) and (2) *Morse tapers* (also from No. 1 to No. 6). The taper value for the former is $t = 1:20$, and for the latter from 1:19.002 to 1:20.048. All dimensions for these tapers are standardized and are given in millimetres.

The USSR Standard sets forth the general rules for dimensioning sketches and working drawings without taking into consideration the production datum surfaces.

Many of these rules were given before. The following are the rules applicable to mechanical drawing.

(1) Painted parts should be dimensioned as if they were unpainted.

(2) If a view has a break, the dimension line must be continuous.

(3) On half-sectioned views dimensioning should be carried out as in Fig. 399 (for instance, d_5).

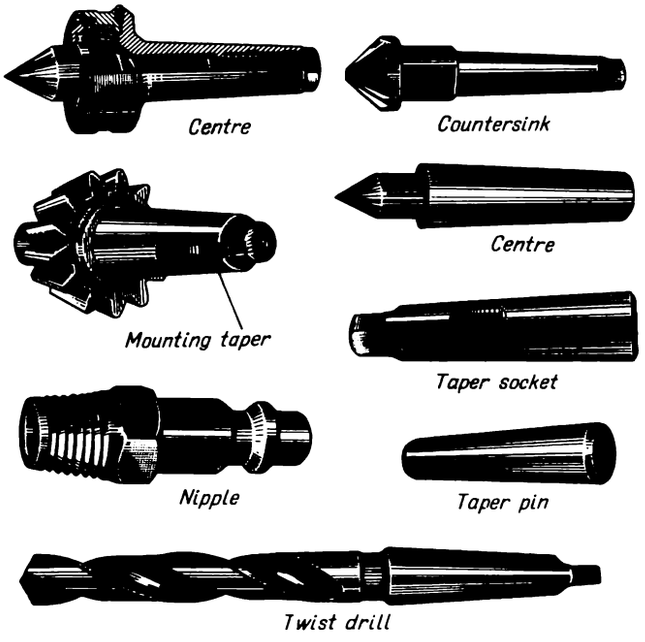


Fig. 400

(4) If a view has a break, then the dimension line must extend somewhat beyond the axis of symmetry or the break.

(5) If there is no place for an arrowhead at the end of a dimension line, a drawing outline may be broken.

(6) If not a whole number, dimensions are given as decimal (not common) fractions, except for some ratios (say, gradients) and dimensions in inches.

(7) Chamfers at an angle of 45° are specified by the dimension of the leg of the right triangle formed by the chamfer, for instance, $2\times45°$ (or $c\times45°$ as in Fig. 399).

(8) Chamfers at other angles are specified by the dimension of the leg of the right triangle and the value of the chamfer angle. In this case abbreviated notation is not allowed.

If a drawing has removed elements showing some elements of the part drawn to a larger scale, then dimensions are placed on these elements.

4. SOME METHODS OF MEASURING MACHINE PARTS. MEASURING TOOLS

The distance between hole centres is conveniently measured with the aid of a steel rule graduated in millimetres. To determine the distance between the centres of two equal holes (Fig. 401*a*) apply the rule with its zero to the edge *m* of one hole and read the required dimension from the rule at the point *n*.

The distance between two holes of different diameters is determined in the following way: first measure the distance *ke* (Fig. 401*b*), then measure the radii of these holes ($d/2$) and add them to *ke*.

Centre-to-centre distances can also be measured by means of measuring tools, such as an outside caliper and inside caliper.

The *outside caliper* with two bent pivoted legs is used for measuring wall thickness, rod diameters, and so on (Fig. 402).

The *inside caliper* with straight legs and bent-out measuring ends is intended for measuring inside dimensions, for instance, hole diameters. Figure 403 illustrates a method of measuring a centre-to-centre distance with the aid of the inside caliper. The required dimension is then read from a steel rule graduated in millimetres.

This method is used when the shape of the machine part to be measured makes it impossible to directly apply the steel rule.

Outside and inside calipers are used to determine the wall thickness of bushes, cups, sleeves, etc., with narrowed or flanged entrances (see Fig. 404).

In this case the wall thickness *c* is determined by simultaneously applying both measuring tools and is equal to the difference of the distances transferred by the outside and inside calipers.

The thickness *k* is determined as the difference

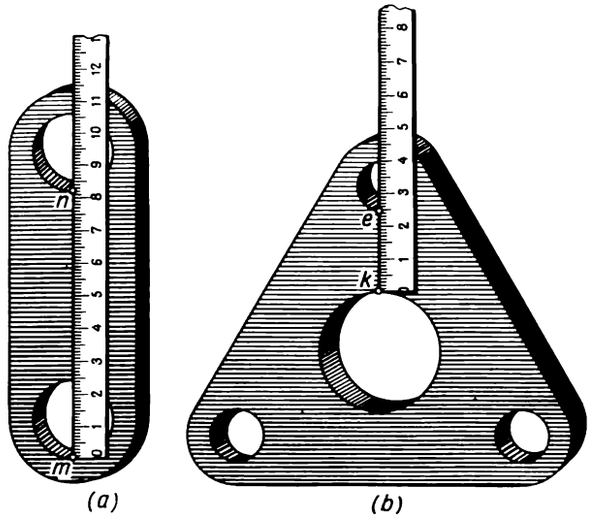


Fig. 401

of two measurements (l and l_1) taken by the steel rule.

Suppose it is necessary to measure the length of a stepped machine part (such as the compressor piston shown in Fig. 405), and only a rule and triangles are available. Then it is desirable to place the part in a horizontal position, and proceed as shown in the figure. This is a very primitive method of measurement and is used only as a makeshift.

Under shop conditions, more precise length measurements (with an accuracy of up to 0.1-0.05 mm) are carried out by means of the *vernier caliper* (Fig. 406). It consists of a steel beam graduated in millimetres, ending in a measuring jaw at a right angle to the beam. Mounted on the beam is the head which slides along it and carries another measuring jaw and a vernier plate with a vernier scale. The head can be fixed on the beam at any position with the aid of a clamping screw *A*.

The vernier scale, or simply vernier, serves for accurately reading fractions of a millimetre on the main scale. Whole millimetres are read on the main or beam scale opposite the zero line of the vernier, while fractions of a millimetre are indicated by the vernier line that coincides with some line on the main scale.

The inside jaw surfaces are meant for external measurements (Fig. 407), and the outside surfaces for internal measurements (Fig. 406).

Shown in Fig. 408 is a *multi-purpose vernier caliper* designed to measure not only internal and external dimensions, but also the depths of holes and the heights of shoulders in holes.

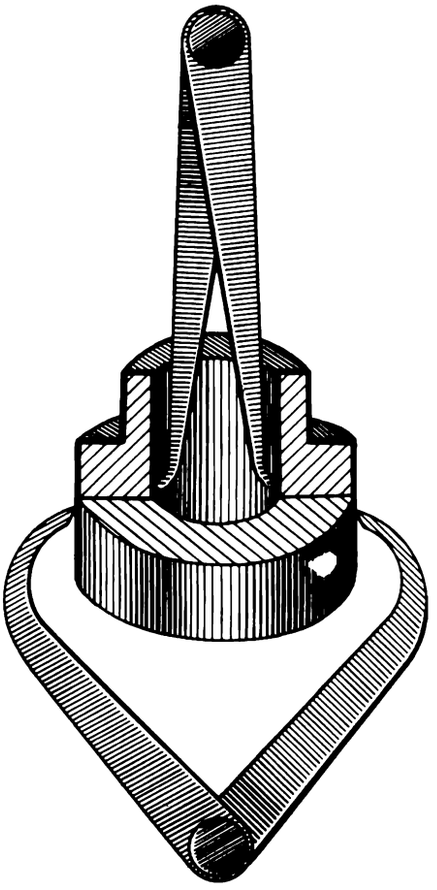


Fig. 402

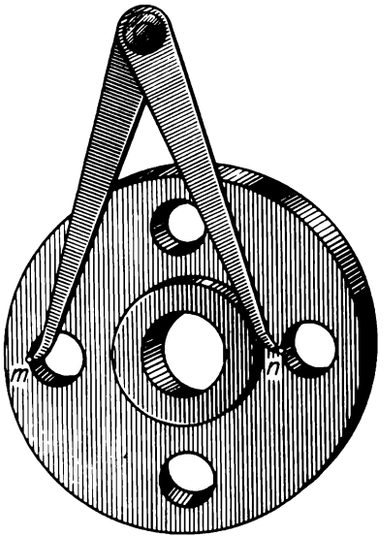


Fig. 403

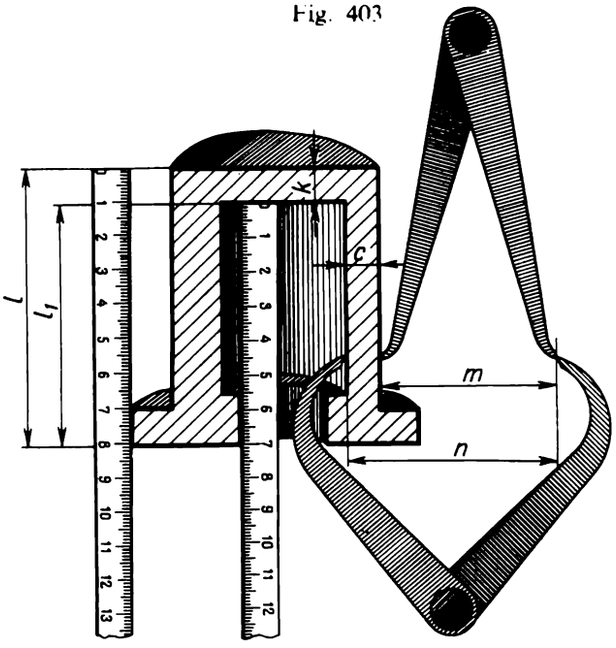


Fig. 404

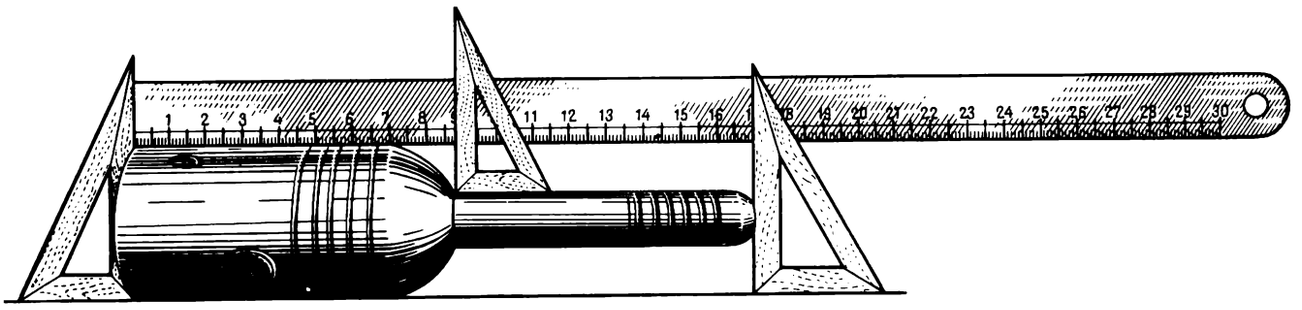


Fig. 405

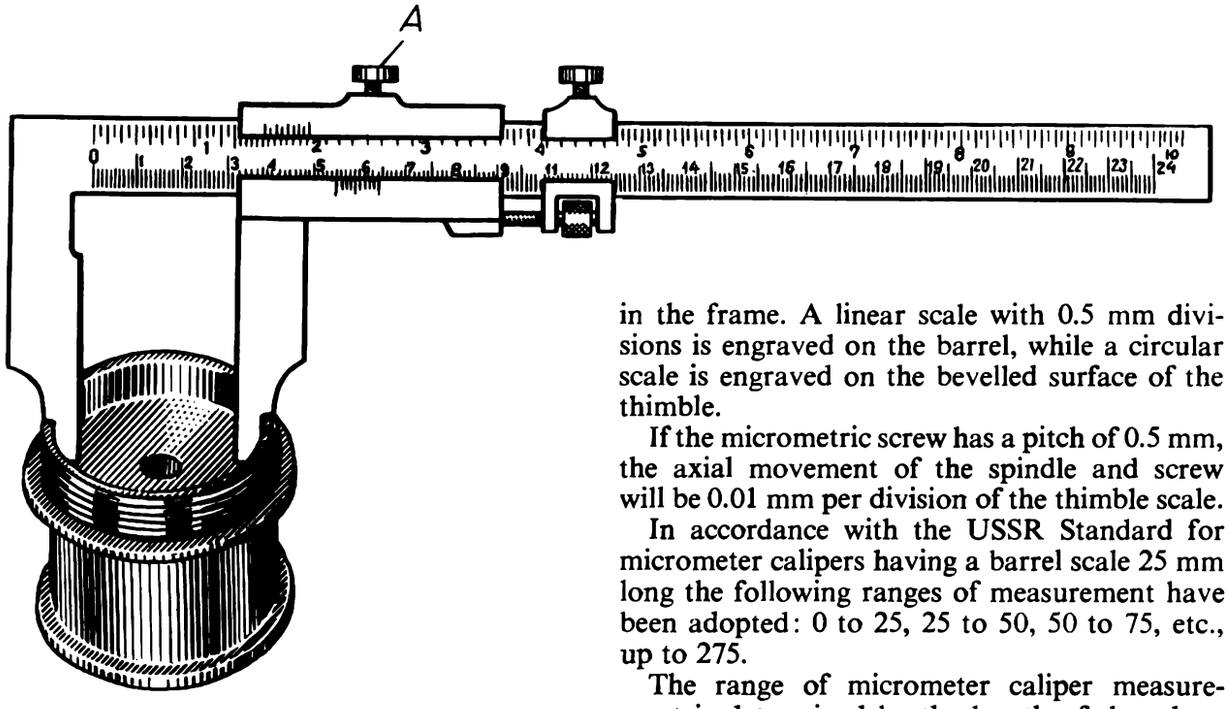


Fig. 406

Still more accurate measurements of part dimensions are made by means of the *micrometer caliper* (Fig. 409), its measuring accuracy being equal to 0.01 mm.

The operating principle of this measuring tool is as follows. A micrometric screw rotates in a fixed nut and travels in an axial direction with reference to the nut. The screw is rigidly fastened to the thimble *b* while the nut is fastened to the barrel *a*. Therefore the thimble rotates and moves axially along the barrel when the screw is rotated.

One measuring face is at the end of the spindle, integral with the screw, the second measuring face is at the opposite side, on the anvil mounted in the frame. A linear scale with 0.5 mm divisions is engraved on the barrel, while a circular scale is engraved on the bevelled surface of the thimble.

If the micrometric screw has a pitch of 0.5 mm, the axial movement of the spindle and screw will be 0.01 mm per division of the thimble scale.

In accordance with the USSR Standard for micrometer calipers having a barrel scale 25 mm long the following ranges of measurement have been adopted: 0 to 25, 25 to 50, 50 to 75, etc., up to 275.

The range of micrometer caliper measurement is determined by the length of thread on the screw. This length, as a rule, does not exceed 25 mm, as the required accuracy cannot be attained with longer threads.

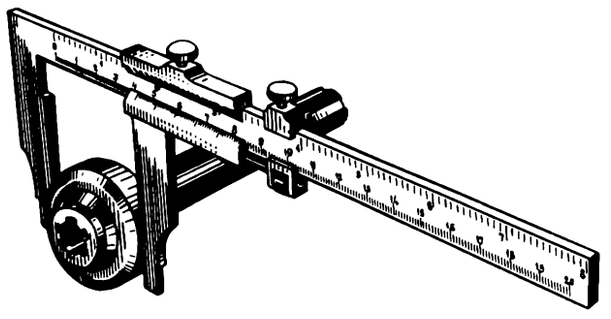


Fig. 407

When taking measurements with a micrometer caliper whole millimetres of a dimension are read on the barrel scale, while hundredths of a millimetre are read from the circular scale on the bevelled surface of the thimble.

Angles and tapers are measured by bevel protractors (Fig. 410).

The bevel protractor has a vernier *A* by means of which readings with an accuracy of 2′ can be obtained. The main scale *B* is graduated in 1° divisions. Illustrated in the figure is the method of measuring angles on a cutting tool.

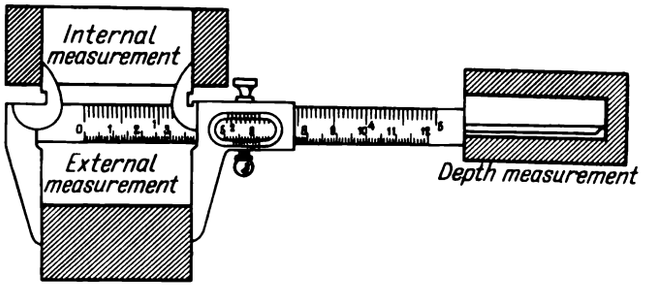


Fig. 408

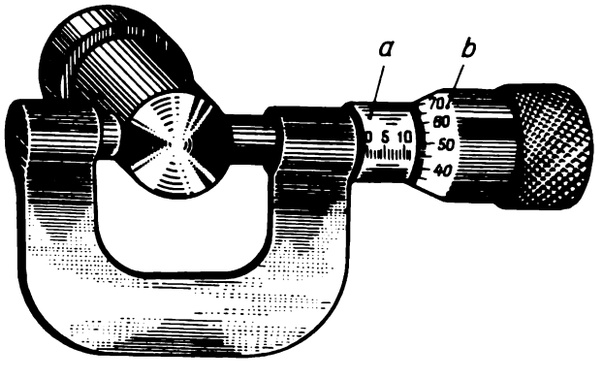


Fig. 409

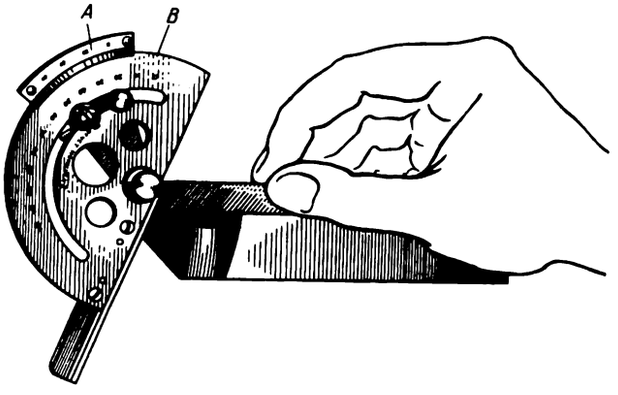


Fig. 410

Limit gauges shown in Figs. 411 and 412 are used during manufacturing mechanical parts for checking certain dimensions: rod diameters and thicknesses are checked by the *snap gauge* (Fig. 411), and hole diameters are checked by the *plug gauge* (Fig. 412).

Shown in Fig. 411 is a double-ended snap limit gauge having two pairs of contacting elements with different distances between them. One distance is equal to the maximum permissible limit dimension. This end of the gauge must freely pass over the rod when checking its diameter. The other distance is equal to the minimum limit dimension specified. This end of the gauge must not pass over the rod.

Holes are checked by *plug limit gauges*, one of which is shown in Fig. 412. Both ends of the plug gauge are provided with cylindrical members. The diameter of one of them is the size of the minimum limit and that of the other is the size of the maximum limit for the given grade of accuracy.

In making sketches it is sometimes necessary to determine the curved outlines of certain machine parts. If such a part has sharp edges and the contour is contained in one plane, then the curved outlines can be transferred to tracing paper, as is shown in Fig. 413, by pressing it against the face of the part and bending the paper over its sharp edges. The dimensions necessary for constructing this curved contour are taken from the imprint thus obtained.

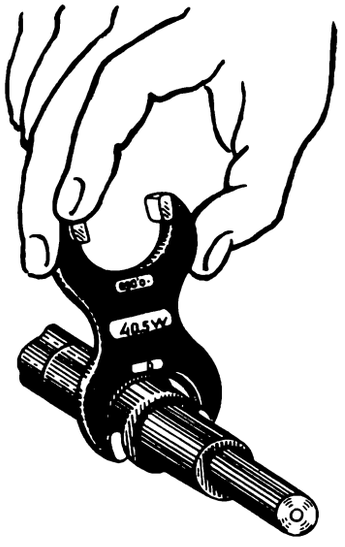


Fig. 411

There are machine parts which have curved contours designed for special purposes that require accurate measurements, for instance, cams (Fig. 414) employed in automatic metall-cutting machine tools.

In such cases the contour outlines are determined by measuring the coordinates of points belonging to the plane curves of the contour by means of a ***shifting gauge*** (Fig. 415), and a ***vernier height gauge*** (Fig. 416), the latter being more precise.

These tools and the work are placed on a surface plate arranged in a horizontal position. To take a measurement the beam of the shifting gauge is brought in touch with the point whose coordinates are to be determined (see Fig. 415).

The height gauge is graduated in millimetres and is fitted with a vernier scale showing fractions of a millimetre that makes this measuring tool more precise and convenient.

Radii of fillets and rounded corners are usually measured by a set of pivoted gauges called fillet and radius gauges (see Fig. 417). Each blade has two straight sides at right angles to one another connected by a tangent arc of the required radius.

Screw pitch gauges are used for checking the pitch of a thread, as well as for approximate determination of thread angles in metric, inch, and pipe triangular threads.

The screw pitch gauge is a set of notched flat steel blades with thread profiles of different pitches (Fig. 418*a*). Blades are pivoted at each end of the holder. In use, the blade with the required thread pitch is applied to the thread being checked (Fig. 418*b*).

Fig. 412

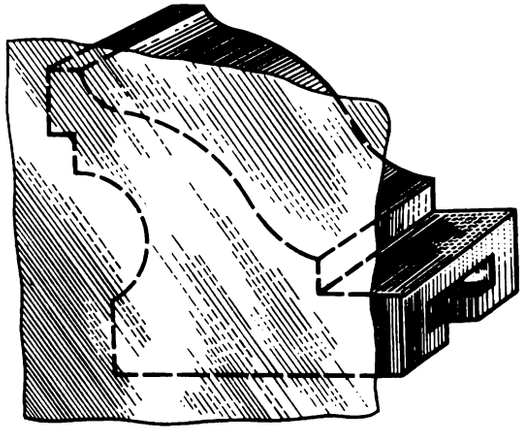


Fig. 413

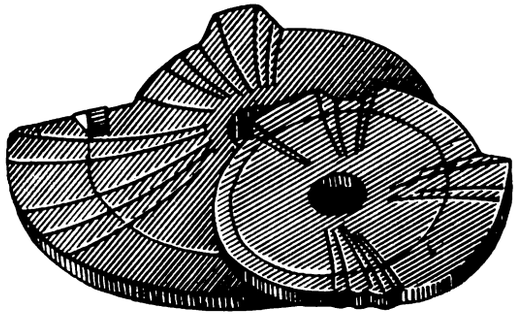


Fig. 414

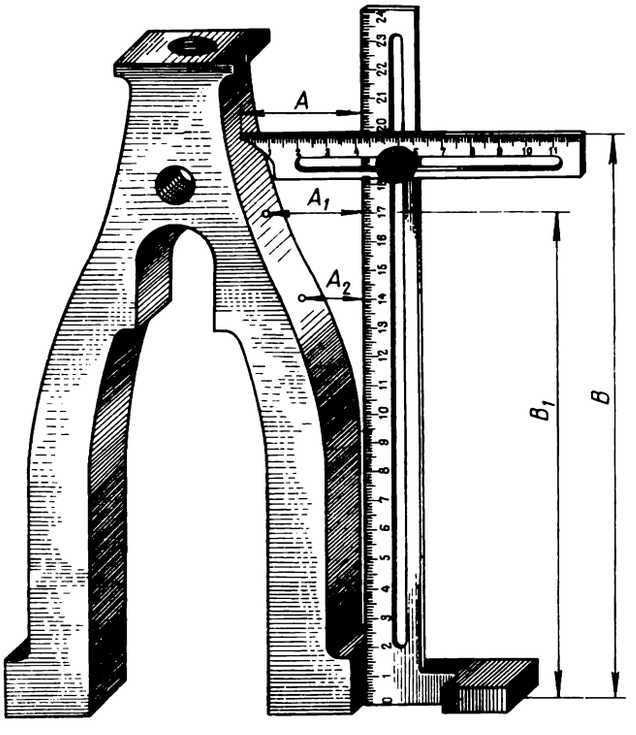


Fig. 415

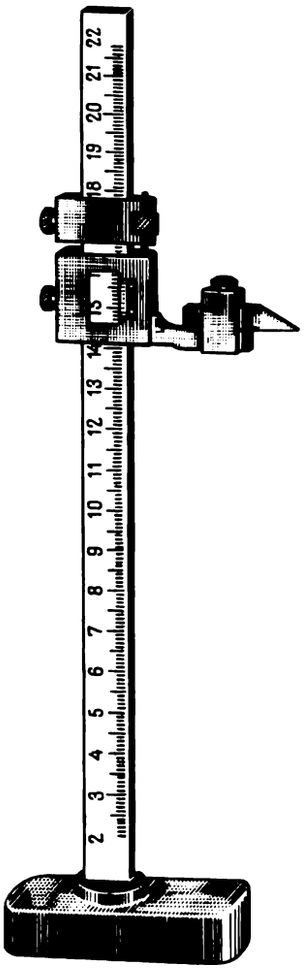


Fig. 416

If the pitch is correct, the gauge will fit tightly to the thread profile, and no light will pass between the thread and gauge profiles (Fig. 418*c*). The screw pitch gauge does not determine the actual value of the pitch error.

Specifications for screw pitch gauges are given in the USSR Standard. One holder usually contains two sets of gauges, one for metric threads with 20 blades (designated as M60°) and the other for inch threads with 16 blades (designated as Д55°).

Dimensions of a thread are determined in the following order. First measure the major diameter, then determine the pitch. Finally, by comparing the results of measurements with the standard values decide whether the thread is standard or special.

Below are two examples illustrating the sequence of operations of measuring threads on cylindrical rods.

1st example. Measuring and identifying the thread of a fastening screw with a cylindrical head.

Suppose the following results are obtained: the major diameter $d \approx 19.5$ mm, the pitch $p \approx 1.5$ mm. The major diameter was measured by means of an outside caliper and a steel rule graduated in millimetres (or by a vernier caliper with an accuracy of 0.1 mm), the pitch with a rule. Two methods are possible here: (1) a steel rule is applied to the screw parallel to its axis, or (2) first the thread is pressed against thick paper to transfer its turns, and then the thread pitch is measured on the paper.

Try to determine the thread type by making

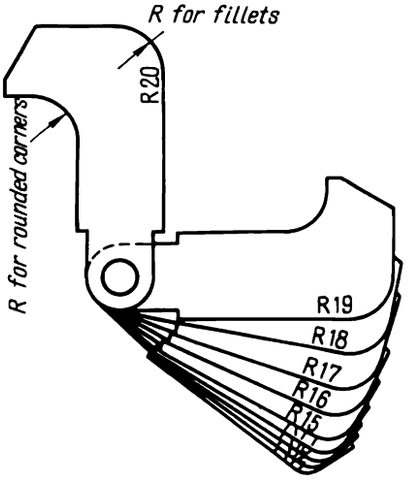
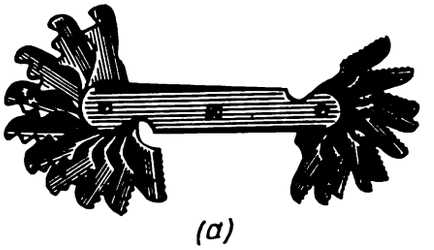
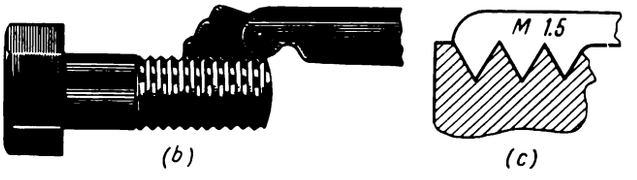


Fig. 417



(*a*)



(*b*) (*c*)

Fig. 418

use of the metric and inch blades of a screw pitch gauge. First apply inch gauges, one by one, until one of them fits tightly to the thread profile.

Referring to the table for inch threads choose the values for the major diameter and pitch which are the closest to those obtained by the measurements; they are: $d_0=19.05$ mm corresponding to 3/4″ thread, and $p=2.54$ mm.

Referring to the table of the USSR Standard for pipe cylindrical threads we find that the nearest major diameter will be $d_0=20.956$ mm with a pitch $p=1.814$ mm. Since the measured pitch considerably differs from the values found, we come to the conclusion that this is not an inch thread.

Now apply the metric blades of the screw pitch gauge to the given thread. You notice that one of them (marked 1.5) ensures a tight fit (see 418*c*), hence the thread is metric. Consulting the USSR Standard *The Basic Dimensions of Metric Threads* we find $d_0=20$ mm and the corresponding pitches: (a) coarse pitch $p=2.5$ mm; (b) fine pitches $p=0.5$ mm, $p=0.75$ mm, $p=1$ mm, $p=1.5$ mm, and $p=2$ mm.

Thus, the thread being measured is a standard metric thread M20 with a fine pitch $p=1.5$ mm. Finally, let us consult the USSR Standard *Screws with Cylindrical Heads* to see whether the screw itself is standard (and not only its thread). Indeed, the above mentioned Standard specifies such screws (M20, $p=1.5$ mm). Therefore both the thread and the screw are of standard size. Such a screw should be designated in drawings as Screw M20×1.5×Length.

2nd example. Measuring and identifying the trapezoidal thread of a motion screw. The measured major diameter $d_0=37$ mm, the measured pitch $p=6$ mm. Place the screw in a vertical position to determine the direction of the thread. The thread turns out to be right-hand. Insert the pencil point in the thread groove and make a complete turn to determine whether it is a single or multiple thread. Since the pencil has missed one groove, this is a double thread. Take the nearest values for the major diameter and pitches from the USSR Standard: $d=38$ mm, the corresponding pitches being: $p=10$ mm, $p=6$ mm, and $p=3$ mm. These dimensions are specified for a right-hand, trapezoidal single thread with a fine pitch. According to the USSR Standard the same profile is specified for a left-hand double thread.

5. DESIGNATION OF SURFACE CHARACTERISTICS

If we look at the surface of a machine part through a magnifying glass or a low-power microscope, we can see that it is not smooth and uniform and that it has irregularities in the form of small peaks and valleys (micro-irregularities). The totality of these irregularities, making up the relief of the surface over a definite *roughness-width cutoff* l*, is called the *surface roughness.*

On some surfaces of parts the irregularities are visible with the naked eye, on others, only by means of instruments. In such cases we say that the surfaces have different roughness ratings.

A section normal to a surface gives an idea of its profile, or contour: the number, shapes and sizes of the peaks and valleys of the irregularities (see the diagram in Fig. 419). Standards of various countries stipulate that the surface roughness shall be specified by one of the following parameters: the *mean deviation of the profile* R_a or the *height* R_z *of irregularities (roughness height).* The values of these parameters are determined within the limits of some portion of the surface, called the roughness-width cutoff l.

If we know the shape of the surface profile (Fig. 419) within the limits of the roughness-width cutoff l, we can draw the median line OX, parallel to the general direction of the profile, with the peaks above the line and the valleys below it.

In Fig. 419, the parameters concerning the valleys are primed (y', A' and h'), while those concerning the peaks are not (y, A and h). The median line is drawn so that the areas contained between it and those parts of the profile that lie on either side of it are equal: $A_1+A_3+A_5+A_7+A_9=A_2+A_4+A_6+A_8+A_{10}$. The mean deviation R_a of the surface profile is the arithmetic mean of the distances of points on the peaks (y_1, y_2, etc.) and in the valleys (y_1', y_2', etc.) from the median line. Only the absolute value (magnitude) of the distances are taken, disregarding the sign. Thus, the mean deviation is

$$R_a=\frac{(y_1+y_2+y_3+\ldots+y_{n-1}+y_n)}{2n}$$
$$+\frac{(y_1'+y_2'+y_3'+\ldots+y_{n-1}'+y_n')}{2n}$$

* Called the sampling length in the British standard.

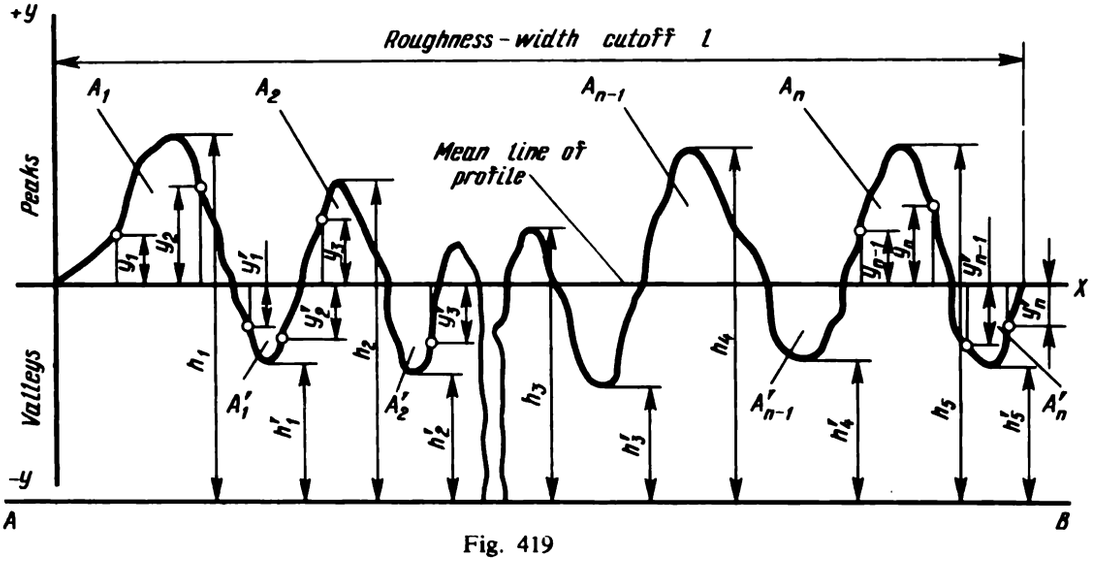


Fig. 419

where $2n$ is the total number of distances measured.

The roughness height R_z (found on the basis of ten points) is defined as the mean distance (peak to valley) between five of the highest peaks and five of the lowest valleys within the roughness-width cutoff, measured from an arbitrary line AB parallel to the median line OX (Fig. 419). Thus

$$R_z = \frac{(h_1 + h_2 + h_3 + h_4 + h_5) - (h'_1 + h'_2 + h'_3 + h'_4 + h'_5)}{5}$$

Surface roughness, expressed by R_a values, can be measured directly by means of special instruments called profilometers. Another stylus-type instrument called a profilograph records the profile of the surface (profilogram) from which the R_z value can be determined.

The degree of surface roughness is specified by the *class of surface finish*. The pertinent USSR standard provides for various classes of surface finish (roughness) for metals, plastics and other materials, with the exception of those having a nap* (for instance, felt). There are fourteen such classes. Each class of surface roughness corresponds to a definite range of roughness values, expressed as R_a or R_z, and a definite roughness-width cutoff l (see Table 15). Roughness classes from 6 to 14, inclusive, are subdivided into series.

As is evident from Table 15, roughness classes from 1 through 5, and 13 and 14 are specified by parameter R_z. Classes from 6 to 12, inclusive, are specified by parameter R_a.

The USSR surface roughness standard agrees with the recommendations of the CMEA (Council of Mutual Economic Aid) standard and with the ISO (International Organization for Standardization) recommendations.

The surface roughness of wood and ligneous materials is specified by twelve classes established by the pertinent USSR standard.

The standards of many countries stipulate surface-quality symbols that are to be used in drawings for indicating the surface finish required. The USSR standard covers all branches of industry (with a separate standard for wooden components).

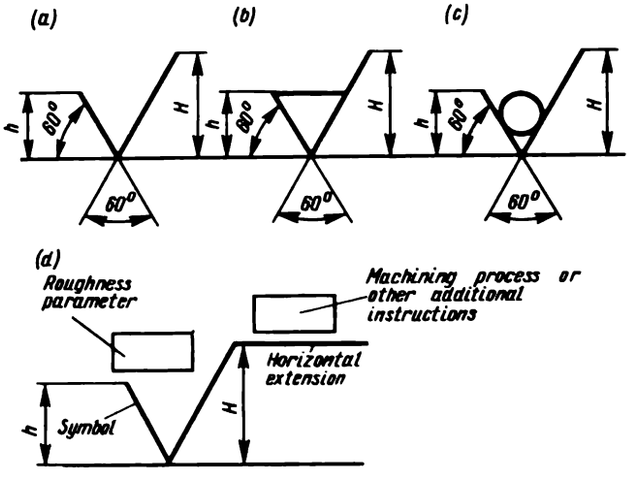


Fig. 420

* A nap is the hairy surface of a material formed by short hairs or fibres projecting from it.

Surface-quality symbols for Soviet drawings are shown in Fig. 420.

Where it is necessary to specify the maximum roughness that can be permitted on a certain machined surface of a part, corresponding to a definite class assigned by the designer, the desired surface finish is indicated on the surface in the drawing by means of a symbol in the form of a radical sign (or a check mark with a horizontal extension). The specified roughness parameter is enclosed in a rectangle drawn above the symbol.

In training drawings, surface-finish designation may be simplified. Instead of the radical sign, only a 60° V symbol, with a shortened left leg and no horizontal extension, is drawn (see Fig. 421). In addition, only one of the roughness parameters, R_a or R_z, is specified (Fig. 421).

The height h of the left leg of the symbol is to be approximately equal to that of the numerals in the dimensions of the drawing (Fig. 420). The height H of the right leg is to be (1.5 to 3) h. The thickness of the lines of the symbol are approximately equal to one-half of that of the thick continuous lines used for the visible outlines of the drawing.

As a rule, surface-quality symbols are placed either on the outline indicating the surface, on extension lines or on leaders with an arrowhead touching the contour view (Fig. 421). The lower vertex of the symbol should touch the line representing the surface it concerns and the V should be positioned so that its bisector is perpendicular to this line.

In cases where the space is limited, the surface-quality symbols may be placed on extension and dimension lines or their continuations, or an extension line can be interrupted as shown in Fig. 421. Symbols may be placed on a hidden outline only if a dimension is specified from this line.

If the designer does not specify the machining process for a surface (leaving it to the processing engineer), then the sign shown in Fig. 420*a* is used.

In specifying the finish of a surface obtained after removing a layer of material by turning, milling, drilling, broaching, reaming, grinding, etc., the symbol used is an equilateral triangle with one extended side (Fig. 420*b*).

The quality of a surface obtained without removing a layer of material (chipless process), i.e., by casting, forging, die-forging, rolling, wire-drawing, etc., is specified by the unequal-leg V symbol with an inscribed circle (Fig. 420*c*).

Table 15

Classes of Surface Roughness
(USSR Std.)

Class	Series	Roughness parameter, micrometres		Roughness-width cutoff l, mm
		R_a	R_z	
1	—	—	from 320 to 160	8.0
2	—	—	from 160 to 80	
3	—	—	from 80 to 40	
4	—	—	from 40 to 20	2.5
5	—	—	from 20 to 10	
6	a	from 2.5 to 2	—	0.8
	b	from 2 to 1.6	—	
	c	from 1.6 to 1.25	—	
7	a	from 1.25 to 1.0	—	
	b	from 1.0 to 0.8	—	
	c	from 0.8 to 0.63	—	
8	a	from 0.63 to 0.5	—	
	b	from 0.5 to 0.4	—	
	c	from 0.4 to 0.32	—	
9	a	from 0.32 to 0.25	—	0.25
	b	from 0.25 to 0.2	—	
	c	from 0.2 to 0.16	—	
10	a	from 0.16 to 0.125	—	
	b	from 0.125 to 0.1	—	
	c	from 0.1 to 0.08	—	
11	a	from 0.08 to 0.063	—	
	b	from 0.063 to 0.05	—	
	c	from 0.05 to 0.04	—	
12	a	from 0.04 to 0.032	—	
	b	from 0.032 to 0.025	—	
	c	from 0.025 to 0.02	—	
13	a	—	from 0.1 to 0.08	0.08
	b	—	from 0.08 to 0.063	
	c	—	from 0.063 to 0.05	
14	a	—	from 0.05 to 0.04	
	b	—	from 0.04 to 0.032	
	c	—	from 0.032 to 0.025	

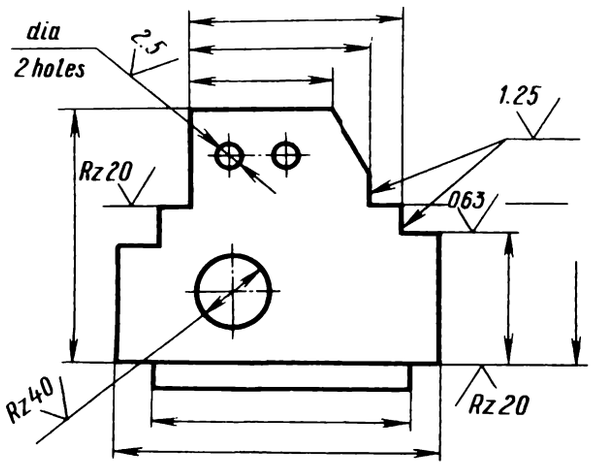


Fig. 421

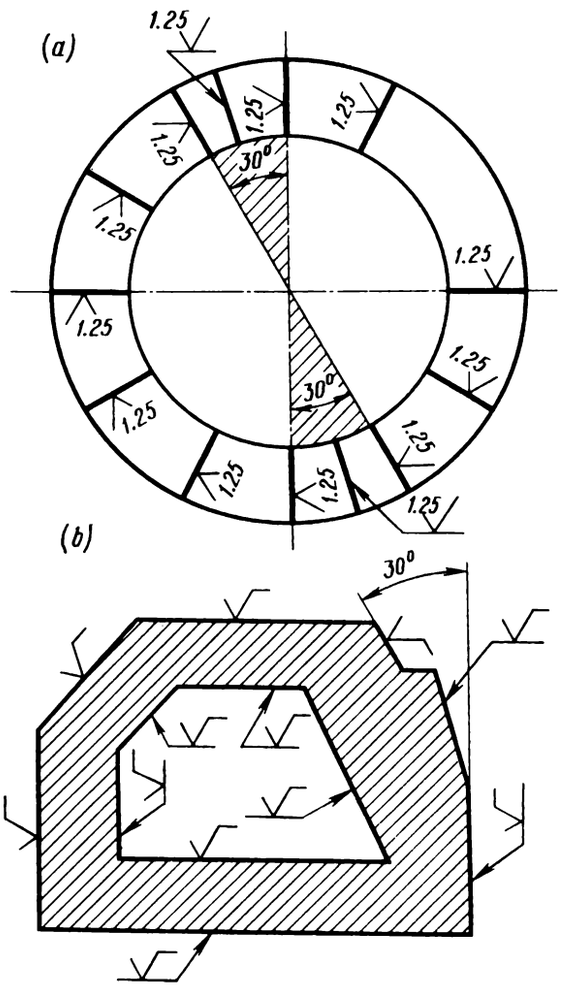


Fig. 422

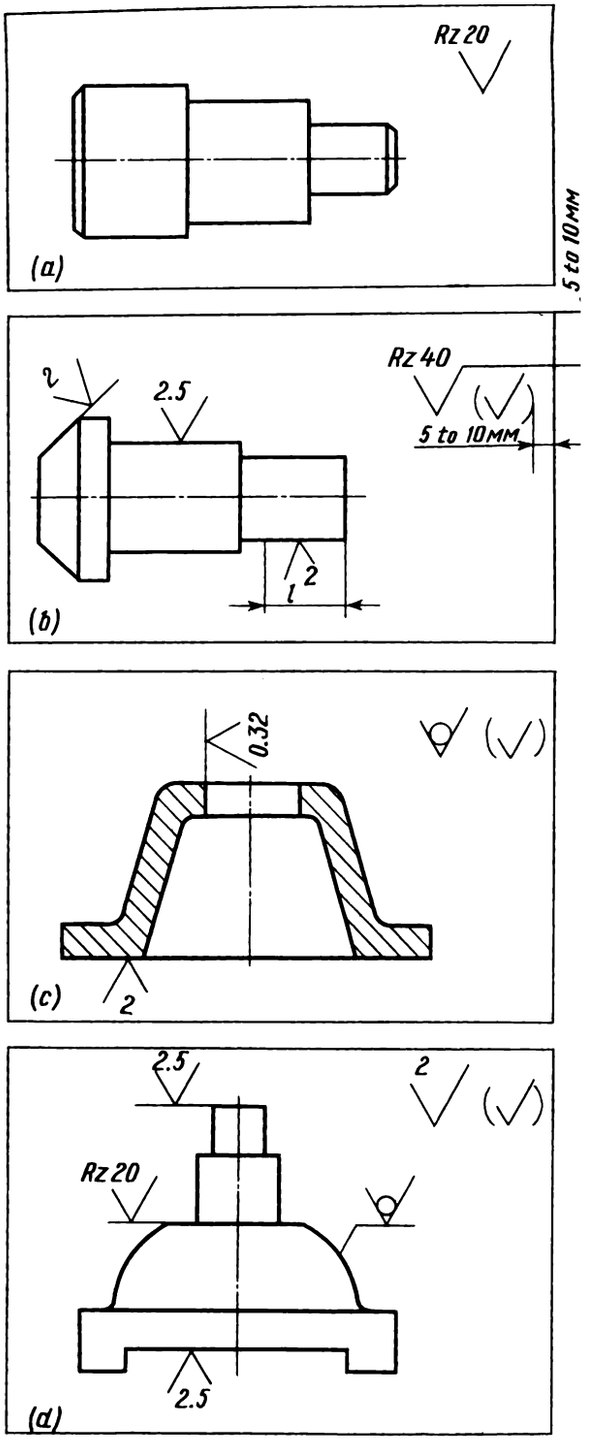


Fig. 423

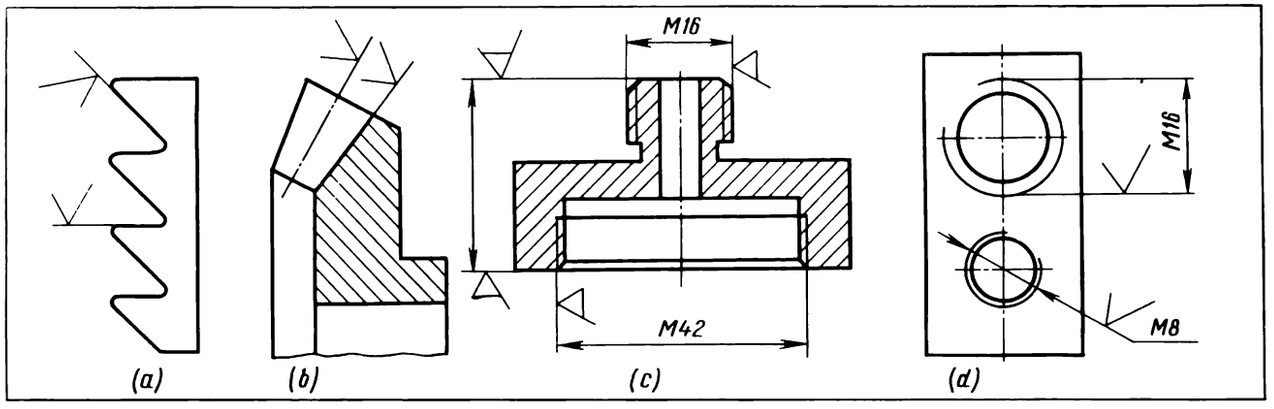


Fig. 424

The surface roughness parameter is indicated as follows: for parameter R_a the letter symbol is omitted and only the numerical value is shown, for example, 1.25. Both the letter symbol and numerical value are specified for R_z parameters, for instance, R_z 20.

The height of the letter symbol and figures should be equal to that of the numerals in the dimensions, and the roughness specification should be arranged as shown in Fig. 421.

The surface-quality symbol should be positioned as near as possible to the dimension line referring to the same surface.

With respect to the title block, surface-roughness symbols should be placed as shown in Figs. 421 and 422. Shown in Fig. 422*a* is the arrangement for symbols having no extension (with only the unequal-leg V). The symbols in Fig. 422*b* have such an extension. If the surface is in a hatched zone (Fig. 422*a*), the symbol is placed only on a leader with an arrowhead touching the surface.

If all of the surfaces of the part are to have the same permissible roughness, then its designation is located in the upper right-hand corner of the drawing, and no symbols are shown on the representation (Fig. 423*a*). If the same maximum permissible roughness is to be specified for only some of the surfaces (others having other values), the symbol common to a number of surfaces is followed by a symbol in parentheses (√). This second symbol indicates that all surfaces not having roughness symbols in the drawing are to have a maximum roughness as specified by the symbol preceding the parentheses (see Fig. 423*b* and *d*). The size of the symbol in parentheses is the same as that of the symbols on the representation.

In drawings of parts on which some of the surfaces are not to be machined to the given drawing, the symbol √ is placed in the upper right-hand corner, preceding the symbol in parentheses (√) (Fig. 423*c*). If some surface is to be obtained by a chipless process, the symbol √ is placed on this surface as illustrated in Fig. 423*d*.

The roughness designation for the surfaces of repeated identical elements of parts (holes, slots, teeth, fins, etc.) whose number is specified in the drawing, is given only once, regardless of the number of times the element is represented. The same is true for a single surface shown in various views.

If different maximum roughness values are to be specified for different portions of a single surface, these portions then should be bounded by a thin continuous line, suitably dimensioned (for example, the length of the portion *l* in Fig.

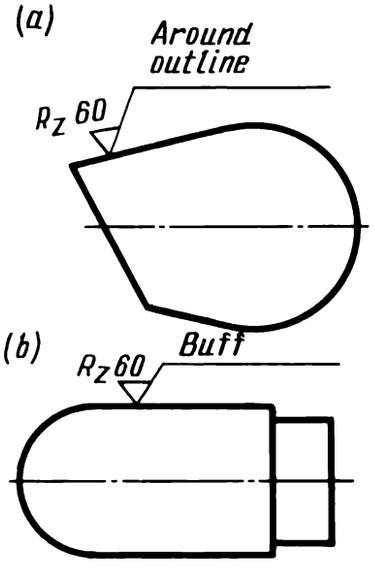


Fig. 425

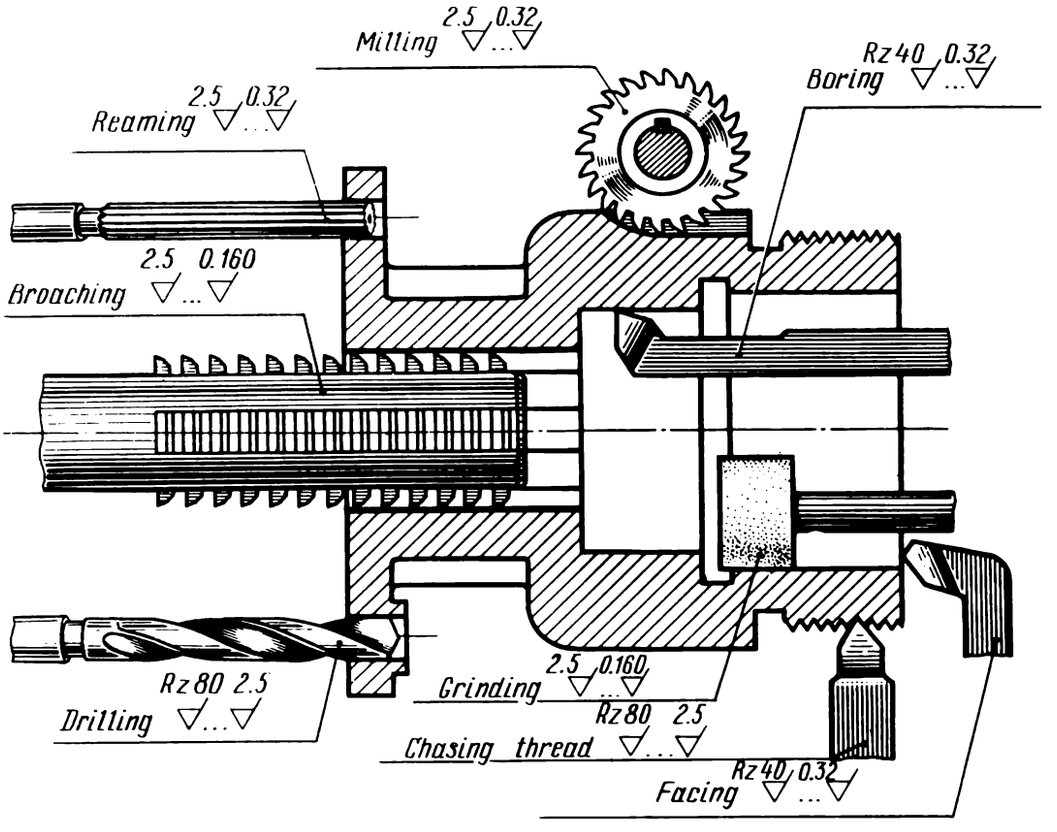


Fig. 426

423*b*), and furnished with the required roughness symbols.

If the profile is not shown separately in a drawing of a gear or involute spline fitting, the permissible roughness value for the working surfaces of the teeth or splines is conventionally specified (only once) on a line representing the pitch surface as shown in Fig. 424*b*.

If a surface, which is an outline of the part, is to have the same finish throughout, the roughness symbol is shown only once with the inscription "*Around outline*" placed above the horizontal extension of the symbol (Fig. 425*a*).

In drawings of parts having helical threads, the roughness symbol for the helical surfaces of the thread is conventionally shown on the extension line indicating the major diameter (nominal size) of the thread or on the dimension line or its continuation (Fig. 424*c* and *d*).

The roughness of a surface depends upon the tool with which it is machined, the machining process, and the cutting variables (speed, feed and depth of cut) used in the machining operation. The approximate ranges of surface roughness associated with various machining processes are illustrated in Fig. 426. The quality of a surface is assigned by the designer on the basis of its purpose and the operating conditions. To properly assign surface roughness values, it is necessary to have a knowledge of manufacturing engineering and some experience in designing.

Before one has acquired such skills, in studying mechanical drawing and in making drawings and sketches of machine parts, the surface roughness may be assigned approximately, using the examples shown in Fig. 427 for guidance. These examples are based on the following considerations.

1. If the contacting surfaces of parts slide on one another, for example, a bearing liner and a shaft journal or the teeth of gears in mesh, these surfaces should have a finish within the 6th through the 9th classes of roughness.

In cases of intensive friction and wear (for instance, wristpins and piston rings, crankpins of crankshafts, cams, etc.), the roughness value assigned should be within the 12th through the 14th classes.

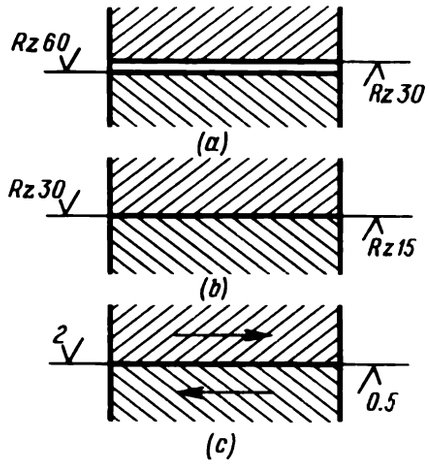


Fig. 427

2. If there is no relative motion between contacting surfaces, their roughness may be from the 3rd through the 6th classes. An example is the surface of a flange joined to a similar flange.

6. TERMINOLOGY OF COMMON MACHINE ELEMENT SHAPES

Many machine parts incorporate similar elements in common use. Here we shall consider some of them.

For example, short cylindrical or conic surfaces of parts provided with holes for bolts, plugs, lubricators, etc., are called *bosses* (Fig. 428*a* and *l*); short bevelled surfaces (Fig. 428*b*, *d* and *o*) at the ends of shafts, axles, rods, bolts,

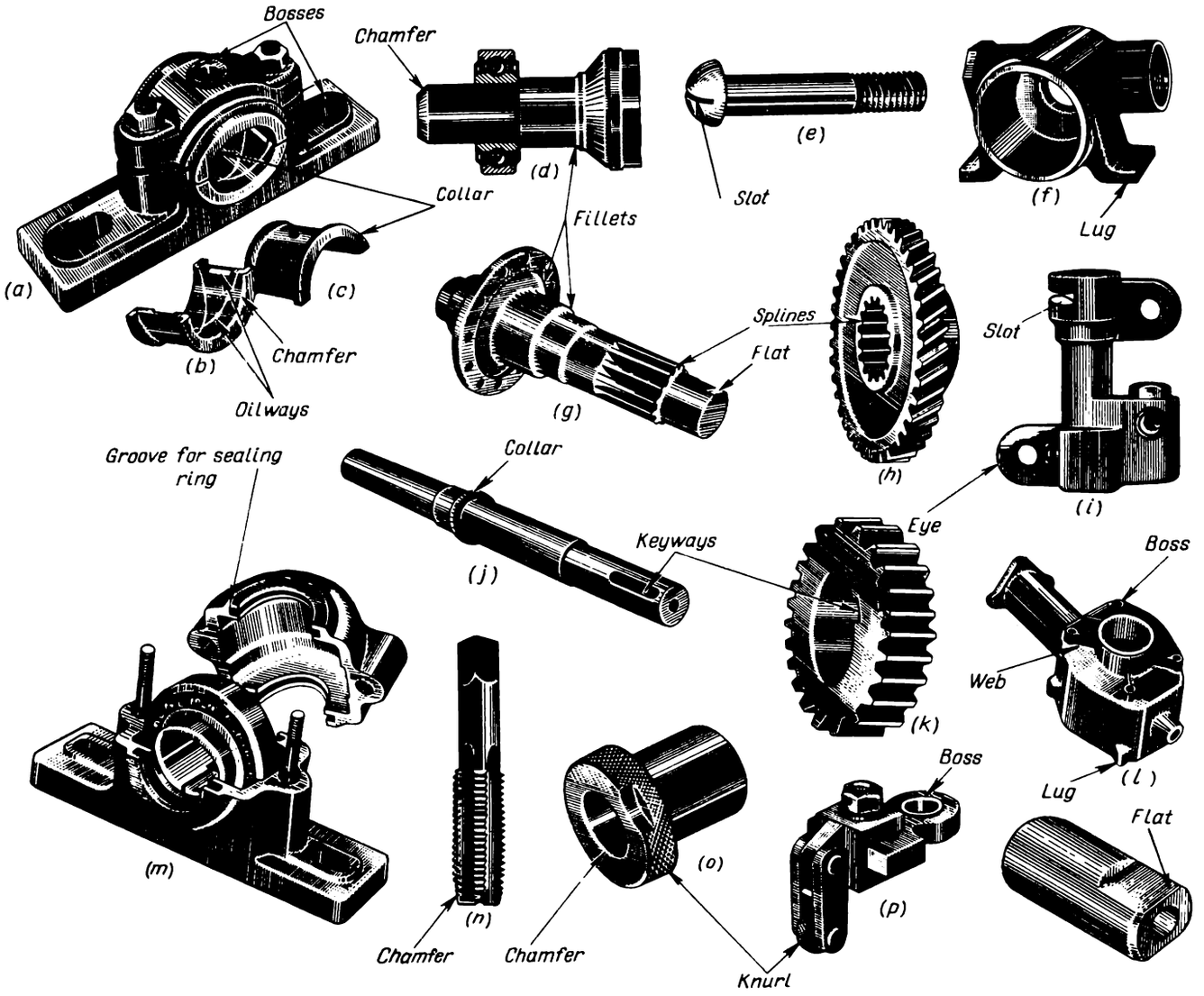


Fig. 428

studs, etc. are called *chamfers;* short surfaces of revolution (Fig. 428*d* and *g*) between two adjoining cylindrical surfaces of different diameters as in shafts, axles, etc., are termed *fillets;* short protruding cylindrical surfaces on shafts and axles (Fig. 428*c* and *j*) are called *collars;* a plane surface transient from one cross section of a shaft or axle to another is called a *shoulder;* short cylindrical or conic surfaces inside a part (as in Fig. 428*m*) are termed recesses or grooves; internal half-round grooves in bearing brasses are called *oilways* (Fig. 428*b*).

Lugs, *eyes*, and *webs* are shown in Fig. 428*f*, *i*, and *l*, respectively. Grooves for keys provided on shafts (Fig. 428*j*) or inside wheel hubs (Fig. 428*k*) are called *keyways.*

Longitudinal projections of rectangular or other profile on shafts and in hubs (Fig. 428*g* and *h*) are called *splines.* Narrow grooves on screw heads for a screwdriver (Fig. 428*e*) are called *slots.* A plane surface cut by a plane from a cylinder side is termed a *flat* (Fig. 428*g* and *q*).

A fluted surface on cylindrical parts is called a *knurled surface*, or *knurling* (Fig. 428*p*). It is obtained on a lathe with the aid of a *knurl* (Fig. 428*p*), which is made of hardened steel.

Shown in Fig. 428*n* is the chamfer of a tap thread.

A drawing of an axle given in Fig. 429 illustrates the following common shapes: chamfer, fillet, shoulder, flat, collar, neck, recess, and vanish thread in a hole. Some of them result from casting, die and drop forging, and some from machining.

It is practically impossible to make an adequate sketch or working drawing of a machine part without being familiar with the production processes. The student must attentively examine separate elements of a machine part, bearing in mind the production process requirements, and represent them in a sketch or a working drawing.

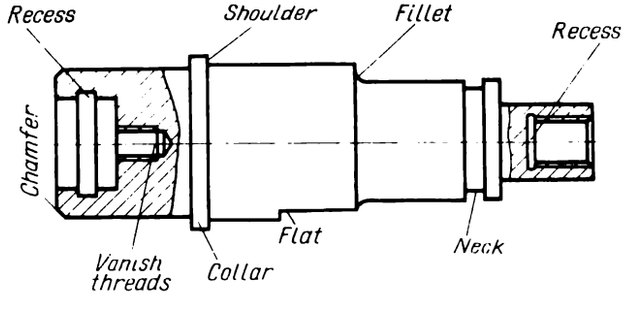


Fig. 429

The following are the most common features to be taken into account:

(a) casting and stamping drafts;

(b) fillets and wedge-shaped variations of cross section;

(c) angular interconnections of walls in castings.

Drafts (or tapers) in parts cast in sand moulds are usually of the order of 1/5 to 1/50 depending on the length and height of the casting.

To avoid casting faults and internal stresses the casting surfaces merge gradually into one another and have no sharp corners.

Steel forgings have drafts ranging from 2° to 15°.

7. MATERIALS AND THEIR DESIGNATION

Many parts are cast from gray iron whose characteristic features are as follows:

(1) Dark-gray colour.

(2) Unmachined surfaces are rough. Surfaces merge gradually into one another. Cylindrical surfaces are replaced by conic ones with a casting draft equal to 2-4%.

A gray iron casting is designated in the following way: СЧ 12-28, where the Russian letters СЧ stand for gray iron, the first figure (12) is the tensile strength in kgf per mm^2, the second figure (28) indicating the bending strength also in kgf per mm^2. The greater the figures, the stronger is the casting.

The grade of the material is usually specified in the division *Material* of the title block. Here is an example of designation for a part made of gray iron: СЧ 18-36.

A steel casting is designated as 30Л, where 30 is the carbon content of the steel in hundredths of one per cent, and the Russian letter Л means casting.

Some parts (such as bearing brasses, bushes, etc.) are cast of bronze which is a dark-yellow alloy of copper and tin with zinc, lead and nickel added. Tin bronze is a very expensive material and it is rarely used nowadays, being substituted by some cheaper materials.

An example of conventional designation of bronze: Бр. АЖМц 10-3-1.5 where А stands for aluminium, Ж for iron, Мц for manganese, indicating that this bronze is alloyed from copper, aluminium, iron, and manganese; the figures

10-3-1.5 give the percentage of aluminium, iron, and manganese, respectively, the balance being copper.

Parts made of brass (an alloy of copper and zinc) are of light-yellow colour. Specific properties of brass are obtained by adding different metals in various proportions. Thus, aluminium increases its corrosion resistance, iron and manganese increase its strength, while manganese, lead and tin make it more wear-resistant. For example, various high-speed gears are made of a brass alloyed from copper, zinc, manganese, tin, and lead.

Brass is conventionally designated in the following way: ЛМцОС 58-2-2-2, where Л means brass, Мц — manganese, О — tin; С — lead; the figures 58-2-2-2 indicate the percentage of copper, manganese, tin, and lead respectively, the balance being zinc.

Brasses in a bearing are poured with an antifriction alloy called babbitt which is an alloy of copper, antimony, and tin. Babbitt is of light-gray colour resembling tin.

Many parts of comparatively simple shapes are made of carbon and alloy steels by machining them from bar stock of forged pieces (Fig. 430). These parts, as a rule, have a smooth glittering surface of light-gray colour.

Carbon steels are specified as ordinary carbon steels and structural carbon steels.

Ordinary carbon steels are available in many grades which are designated as follows: Ст. 0, Ст. 1, Ст. 2, Ст. 3, Ст. 4, Ст. 5, Ст. 6, Ст. 7, where the Russian letters Ст. stand for steel, and the figure indicates the grade of steel (the greater the number, the higher the strength of the steel).

Structural carbon steels are marked in the following manner: 10, 15, 65, 15Г, 70Г, where the figure indicates the average carbon content in hundredths of one per cent; the Russian letter Г conventionally denotes high manganese content.

Parts of moderate thickness which have holes, slots and bends (see Fig. 431*a* and *b*) are made of mild carbon steel sections grades Ст. 1 and Ст. 2 by punching and press bending.

Given below are examples of material designation for steel parts:

(1) A fork made of ordinary carbon steel — Ст. 3.

(2) A spring washer made of structural carbon steel — Ст. 65Г.

Aluminium is widely used in various industries, especially in the aircraft industry due to its low specific weight. It is also alloyed with other metals and used as rolled stock and castings. Here are some examples of such alloys:

(1) *Silumin*, an alloy of aluminium and silicon; it is readily cast and is used for manufacturing parts of intricate shapes such as in various instruments, aircraft and ships; it is also popular in electrical engineering. According to the USSR Standard silumin is designated as АЛ2, where the first letter (А) shows that it is an aluminium alloy, the second (Л) means casting, the figure 2 being a conventional number.

(2) Alloy of *aluminium with silicon and magnesium*, designated АЛ9, is used for manufactur-

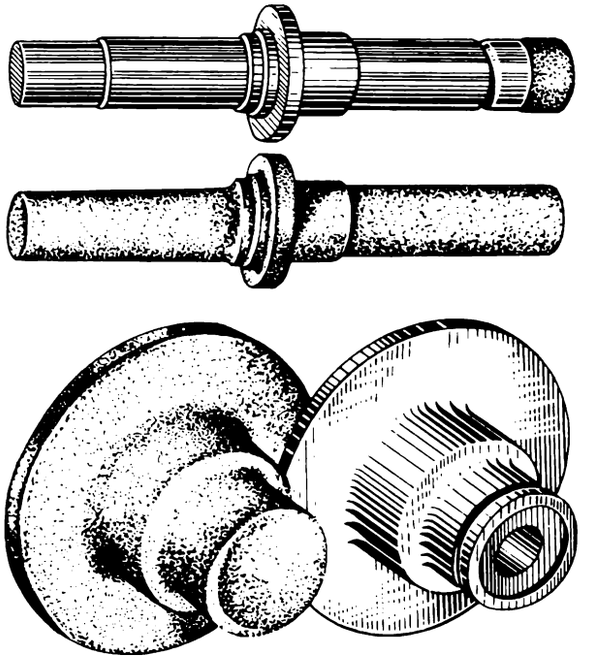
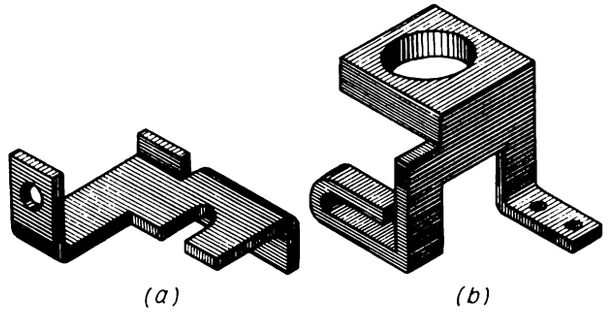


Fig. 430



(*a*) (*b*)

Fig. 431

ing more intricately shaped medium-duty parts. This alloy is readily welded.

(3) *Duralumin*, an alloy of aluminium, magnesium, and copper. It is a very strong and light material, which is readily shaped by forging or rolling.

Nowadays *non-metallic materials* (various *plastics*) have found wide use in mechanical engineering due to their specific physico-mechanical properties and high mouldability.

Parts are made of plastics by injection moulding, pressure moulding, extrusion, welding, bonding, and by many other processes.

Plastics are made of various materials. For instance, the following materials are utilized to obtain *pressed plastics:* impregnated cotton cloth and glass fibre, impregnated veneer and paper, and various ethylene-based materials, such as etrol, polytron, polyvinylchloride, polythene, etc.

Plastics, which are not inferior to metals in strength, replace them in many applications; the specific weight of plastics is five to six times lower than that of steel; they are cheaper and require considerably less time for manufacture. Some plastics possess high acid- and alkali-resisting properties and are extremely wear-resistant. Most popular are parts made of plastics processed in compression moulds from various synthetic resins, for instance, epoxy or phenol-formaldehyde resins, which are obtained from coal tar products, such as benzene, phenol, etc. Some grades of plastics are standardized.

(1) *Laminated wood plastics.* They are designated as ДСП-Б, ДСП-В, ДСП-Г and so on. The Russian letters ДСП mean wood, laminated, plastic. It is made from veneer sheets bonded with artificial resins and pressed together at high temperature and pressure. The letter symbols Б, В, Г indicate the arrangement of veneer sheets in the plastic, for instance, the letter B conventionally means that the directions of fibres are mutually perpendicular in all adjacent layers.

Parts made of wood plastics (pulleys, handwheels, rolls, handles, etc.) are cheap, light, strong, machinable and polishable.

(2) *Stock textolite* (fabric base laminate). This is a widely used laminated plastic obtained by pressing layers of cloth impregnated with artificial resins. Grades of textolite are designated as follows: ПТК (for manufacturing gears), ПТ (for handles), ПТ-1 (for antifriction parts), the letters ПТ meaning stock textolite.

(3) *Vinyl plastic* is a hard sheet material manufactured by pressing plastic films laid in layers. It possesses high anticorrosive and water-resisting properties and is used for piping and fittings. It is highly machinable and can be welded by hot air and joined with adhesives.

Vinyl plastic is available in two grades: ВН — opaque, of natural colour or coloured and ВП — transparent, colourless or coloured.

(4) *Phenoplast* is a phenolic plastic used for manufacturing various parts in pressmoulds by hot pressing. It is conventionally designated as: К-15-2, К-17-2, К-20-2. For example, a knob made of phenolic plastic will be designated in the bill of material as Phenoplast K-17-2.

(5) *Capron* is a plastic utilized for injection moulding of parts possessing high strength, wear-resistance, a low coefficient of friction, high resistance to paraffine, mineral oils, alkalies, and salts.

8. STEPS IN MAKING SKETCHES

In sketching a part from a model do the following:

(1) Determine the working position and purpose of the part.

(2) Choose the main view of the part on the sketch.

The stand shown in Fig. 432 is in a working position. The view facing arrow *A* is chosen as the main view, since it offers the most favourable representation of the shape and dimensions of the part, and besides, all the views on the sketch will be arranged in a convenient manner.

In some cases, to facilitate reading of a working drawing during the manufacture of a part, the main view should show the part in the position occupied by it during the main machining operation. For instance, the axes of axles, shafts, bushes, rods, plugs, gears, pulleys, and other parts should be horizontal on the main view, since they are machined on a lathe in a horizontal position.

(3) Determine the adequate number of external views, sectional views and other section to reveal, as completely as possible, the external and internal shape of the part. In the case under consideration it is sufficient to have three views with a vertical section on the main view.

(4) Estimate by eye the relationship between the overall dimensions of the part and of its principal elements: the base and the upright portion (Fig. 432*a*).

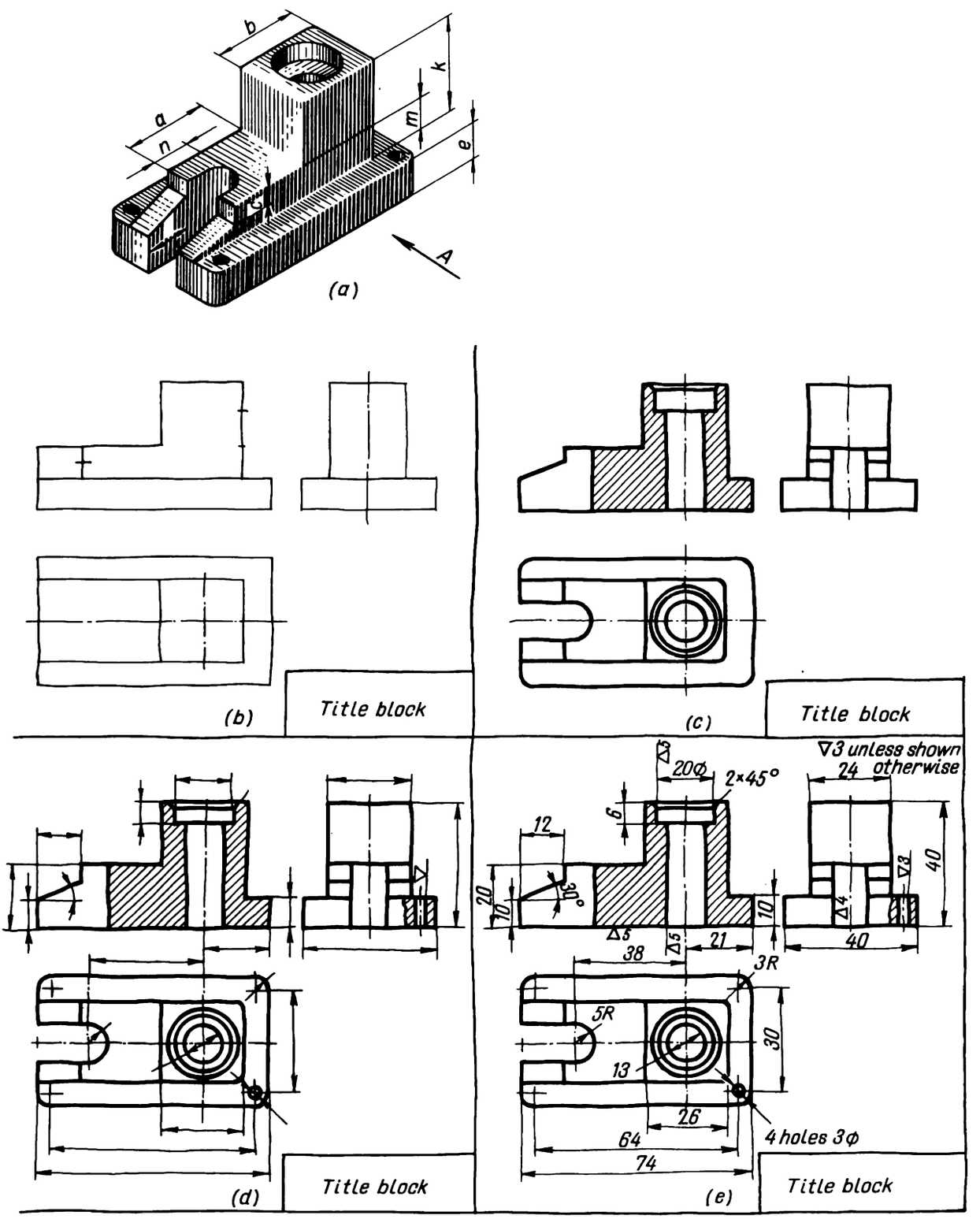

b
a
n
k
m
e
A
(a)
(b)
Title block
(c)
Title block
(d)
Title block
(e)
Title block
∇3 unless shown otherwise
24
20Φ
2×45°
12
6
30°
20
10
10
40
21
38
3R
5R
13
30
26
64
74
4 holes 3Φ

Fig. 432

(5) Choose a scale.

If we take the height (or thickness) of the base (the dimension *e*) as unity, then the dimension *m* will be approximately equal to *e*, *c* to 0.5*e*, *k* to 3*e*, etc.

(6) Construct the main elements of the part by using the estimated proportions of the dimensions (Fig. 432*b*); add the axes of symmetry. All the lines should be drawn free-hand with a soft pencil.

(7) Analyse the part from the geometrical point of view dividing it mentally into separate solids, which are then sketched one by one (Fig. 432*c*). Make the necessary sections.

In our case the stand can be divided into a rectangular parallelepiped (the base) and a similar middle portion bevelled at the left; the upright portion is also a parallelepiped. All inside surfaces are cylindrical and plane.

Having sketched all these elements erase the construction lines, round off the corners, cross-hatch the sections and make the contour lines thick.

(8) Draw the dimension and extension lines (Fig. 432*d*). To this end choose the datum surfaces and lines from which the dimensions will be given. In our case such a surface will be the machined bottom surface. As is seen from Fig. 432*e*, most dimensions are indicated from this reference surface. In addition, it is necessary to give the centre-to-centre distances of the holes, three overall dimensions: the height, width and length of the whole part, and also the diameters of the holes.

The dimension lines should be distributed equally among the three views. The dimension figures should be given so that each dimension could easily be measured by means of standard gauges without resorting to computation. There must be no ambiguity in the dimensions.

The dimensions specifying the internal surfaces should be grouped separately from those of the external surfaces. As far as possible, dimension lines should be drawn outside the contour lines.

(9) Measure the part by means of standard gauges used for training purposes. Some dimensions should be rounded off, taking into account the wear and tolerances.

According to the USSR Standard dimension figures should be written above and parallel to the dimension line and as close to its centre as possible. They may also be written in a gap in the dimension line (see Fig. 433*e*).

Dimension figures should be clear, neat, and sufficiently large; use the characters recommended by the standard. It should be remembered that parts are manufactured according to the dimension figures, and not by measuring the lengths of the contour lines and transferring them from the drawing.

(10) Finally, specify surface finish by making use of conventional symbols; fill in the title block; indicate the manufacturing requirements, etc.

9. MAKING DETAIL (WORKING) DRAWINGS

The working drawings of the parts of a machine are made on the basis of either sketches made from the actual parts or design drawings (general view of the product), or, for training purposes, from training assembly drawings.

Detail drawings are made, as a rule, for almost all the component parts of a given product.

In contrast to a free-hand sketch, a working drawing is made with drawing instruments, to a scale stipulated by the pertinent standard. Such a drawing, signed by all the persons participating in designing, drafting and checking, is called a first draft. Copies of this drawing, obtained by various methods, are called duplicates. Duplicates are reproduced by blueprinting, electrography, or some other technique to obtain the copies required for the lot or mass production of the component part.

The steps in making a detail drawing are practically the same as those required to make a free-hand sketch (see Sec. 8). As mentioned above, the detail drawing differs from the sketch in that it is drawn to a definite scale with the aid of drawing instruments.

When a detail drawing is made from a sketch, the size of the representation may differ from that in the sketch, because the sketch is drawn to an approximate scale, and the drawing, to a definite standard scale.

The form of detail drawings depends to a considerable extent upon the shape of the part and the manufacturing process by which it is to be made (by casting, machining with various machine tools, etc.). The examples below show how the detail drawings of parts having various typical features are to be made.

(a) *Detail Drawings of Parts Manufactured in Machine Tools*

A substantial number of machine parts are bounded by surfaces of revolution: shafts, bushings, sleeves, wheels, disks, flanges, etc. Such parts (or blanks for them) are chiefly made in lathes or other types of machine tools operating on the same basic principle (machining by turning).

On drawings, such parts are arranged so that their axis is parallel to the title block (Fig. 433). If the part is to be turned in a centre lathe or engine lathe, this arrangement proves most convenient for the lathe hand.

Illustrated in Fig. 434 is a sleeve which is fully machined in various machine tools, the majority of the operations being accomplished in a lathe. This detail drawing consists of three views: a frontal section, a profile section and a removed element. The profile section is required to show the shape of the flat and its dimension. The removed element clarifies the shape and dimensions of the recess.

The maximum permissible roughness of the various surfaces is specified by symbols. The remaining surfaces, for which no symbol is

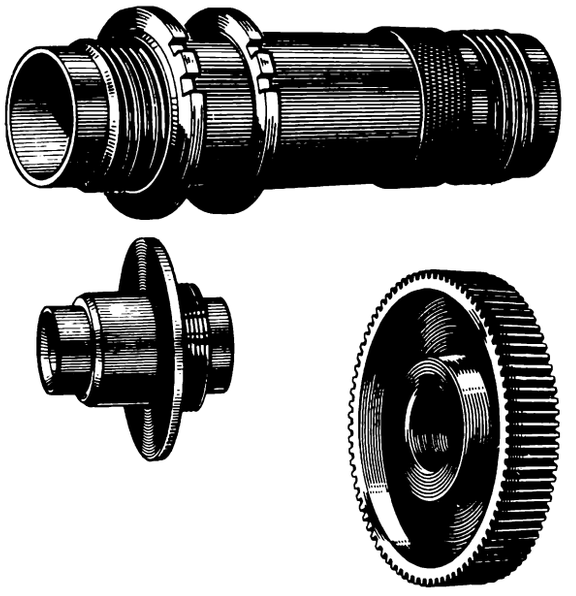


Fig. 433

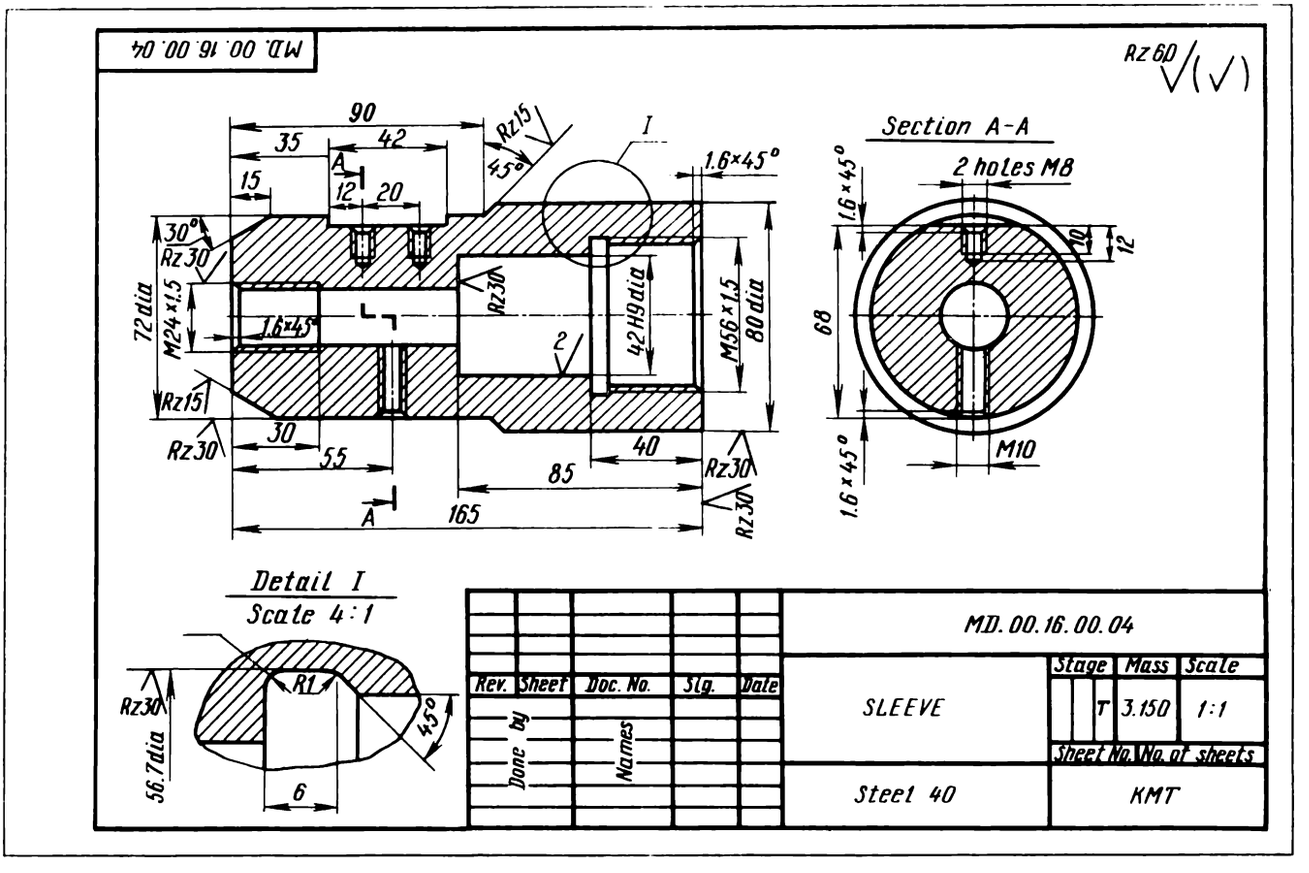


Fig. 434

shown, may have a roughness not exceeding R_z60, as is indicated by the symbol preceding the parentheses in the upper right-hand corner of the drawing.

The dimensions and tolerances enable the part to be machined and then checked in inspection.

(b) *Detail Drawings of Parts Manufactured by Foundry Processes*

An example of a gray-iron bracket made by casting with subsequent machining is shown in Fig. 435.

The drawing has three views: a front view (with broken-out sections), a top view (with a half-sectional view of the cylindrical element of the part) and a bottom view (view facing arrow *A*). In addition, there is a detail section *(Section B-B)* indicating the shape of the casting in the cutting plane.

The maximum permissible roughness of the machined surfaces is specified by the corresponding roughness value symbols. The symbol in the upper right-hand corner of the drawing indicates that all the surfaces obtained in casting may have a roughness not exceeding the specified value (R_z).

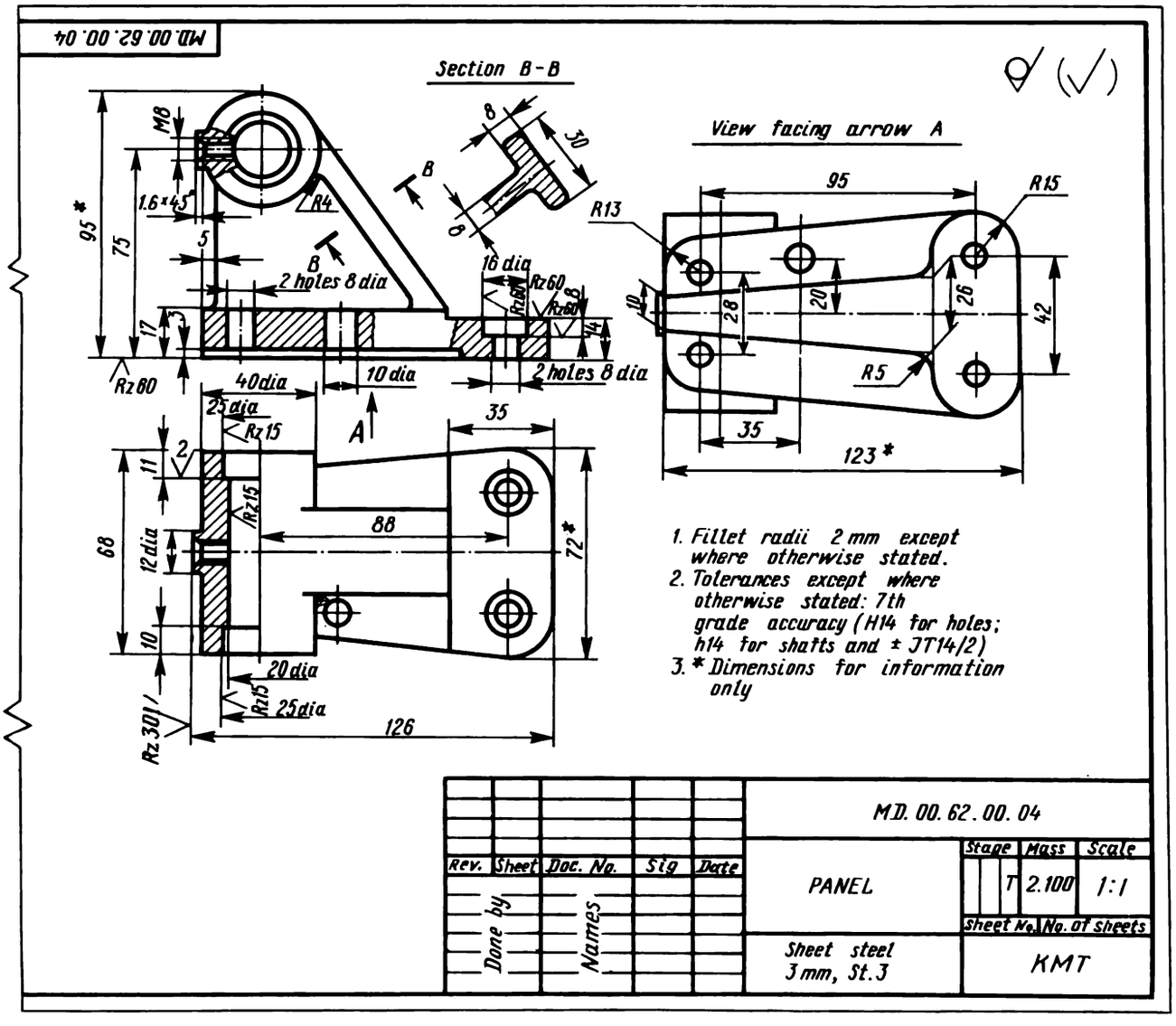


Fig. 435

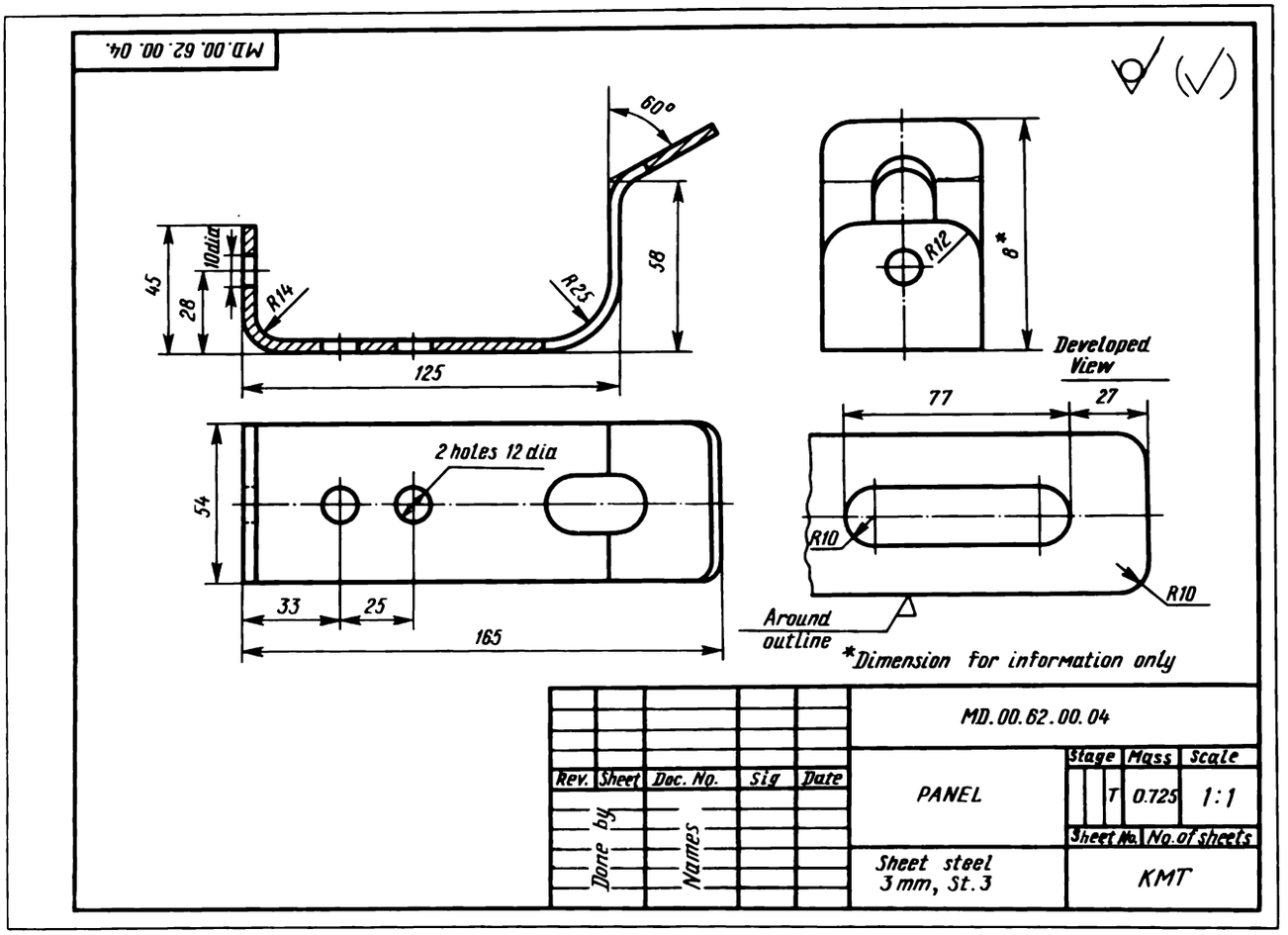


Fig. 436

(c) *Detail Drawings with Developed Views*

A drawing of a panel is given in Fig. 436. It is made by bending a strip of sheet stock in which an elongated hole, or slot, has already been cut out. The three views of the panel and their dimensions do not give a complete idea of the shape of this slot and, consequently, a *partial developed view* is added.

Partial or complete developed views should be given in all cases where the regular views of a part manufactured by bending operations cannot provide full information on the shape and dimensions of certain elements of the part. The developed view should indicate only dimensions that cannot be shown on the regular views of the finished part.

Developed views are shown with thick continuous lines, of a thickness equal to that of the visible outlines on the other views. The note "*Developed View*" is to be written above this view. If necessary, the line of the bend can be shown on the developed view with a thin continuous line and the leader "*Bending Line*".

If possible without impairing the clarity of the drawing, it is permissible to combine a partial developed view with the main view of the

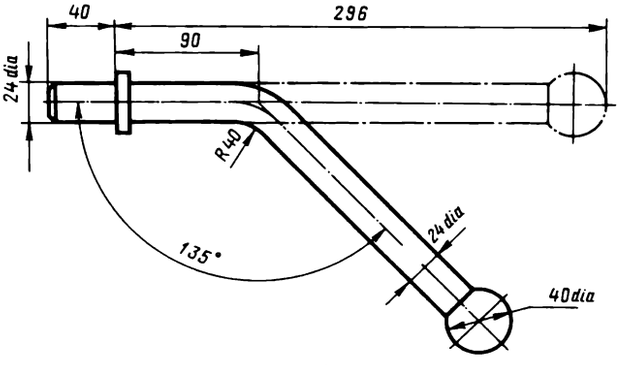


Fig. 437

part. In this case, the developed element is drawn with thin long-chain lines and the note "*Developed View*" is not indicated (Fig. 437).

(d) *Detail Drawings of Springs*

Springs are used to apply a force in instruments, apparatus, machine tools and other machinery. When a spring is deformed, forces are developed in it (internal elastic forces) that tend to restore the initial shape and size of the spring. These are the forces that are made use of in various mechanisms. According to their shape, springs can be classified as cylindrical helical (Fig. 438*a*, *b* and *c*), conical (Fig. 438*d*), flat spiral power, Belleville and other types. With respect to their purpose, springs are designed for compression (Fig. 438*a*, *b*, *d* and *e*), tension (Fig. 438*c*), torsion and bending.

The rod or wire of a helical spring may be of circular (Fig. 438*a*, *c* and *d*), square (Fig. 438*b*) or rectangular (Fig. 438*e*) cross section.

Springs may be wound either right- (Fig. 438*b*) or left-hand (Fig. 438*a*).

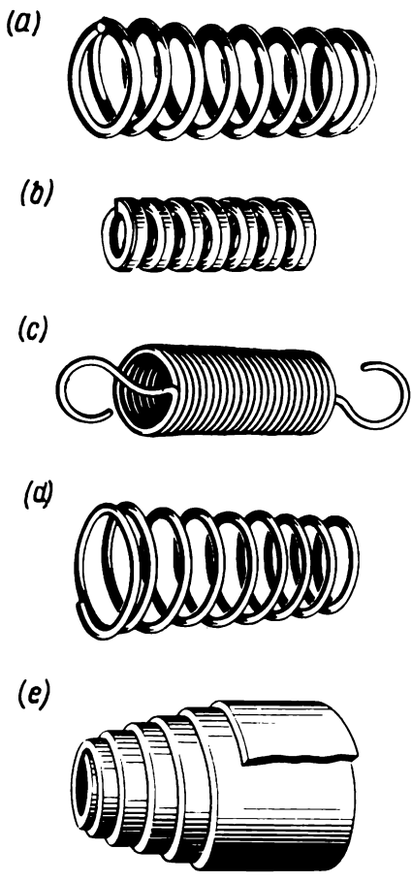


Fig. 438

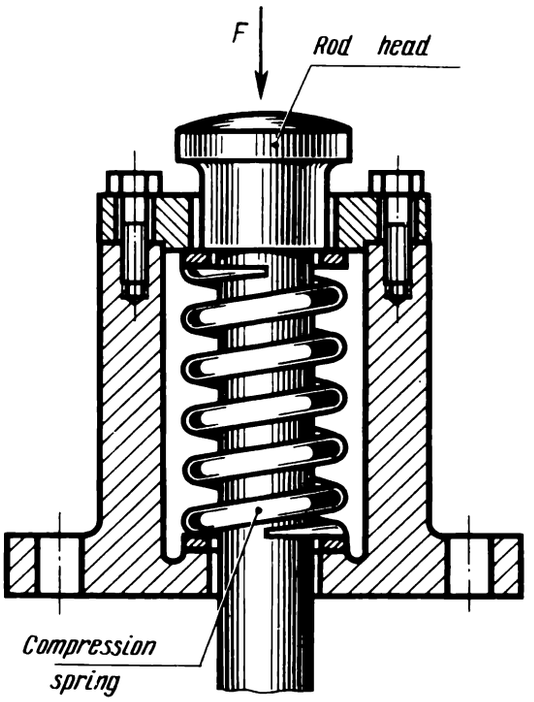


Fig. 439

The springs drawn in the drawing course are mostly helical and of circular cross section. Such springs are wound of round wire or thin bar stock.

A shock absorber with a compression spring is illustrated in Fig. 439. If some moving part strikes the head of the shock absorber rod, the spring is subjected to force *F* and absorbs a part of the kinetic energy of the moving part.

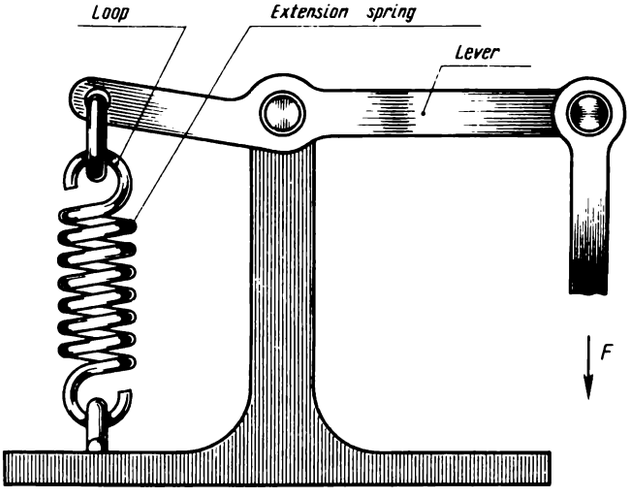


Fig. 440

The tension spring shown in Fig. 440 has its hooks engaged to a device for withstanding the force F applied to a lever.

Drawing practice standards establish rules for conventional representations of springs and for their detail drawings. Examples of training drawings are given in Fig. 441 (compression spring) and Fig. 442 (tension spring).

All springs are shown in drawings in their free state, i.e., not subject to external forces. Regardless of their position in operation, all helical springs are shown with their axis parallel to the title block.

In the projection plane parallel to the spring axis, the sine curves depicting the coils of the spring are replaced by straight lines connecting the corresponding parts of the outline or cross section of the coil.

Closed or closed and ground ends on compression springs provide good bearing against the seats to reduce the tendency to buckle. Such ends are made by closing (bending down) a whole coil or three-fourths of a coil at each end of the spring and then grinding the end over three-fourths of its circumference. As a result, the spring has 2 or 1.5 closed and ground coils (inactive coils) in addition to its active coils. The most extensively used springs have

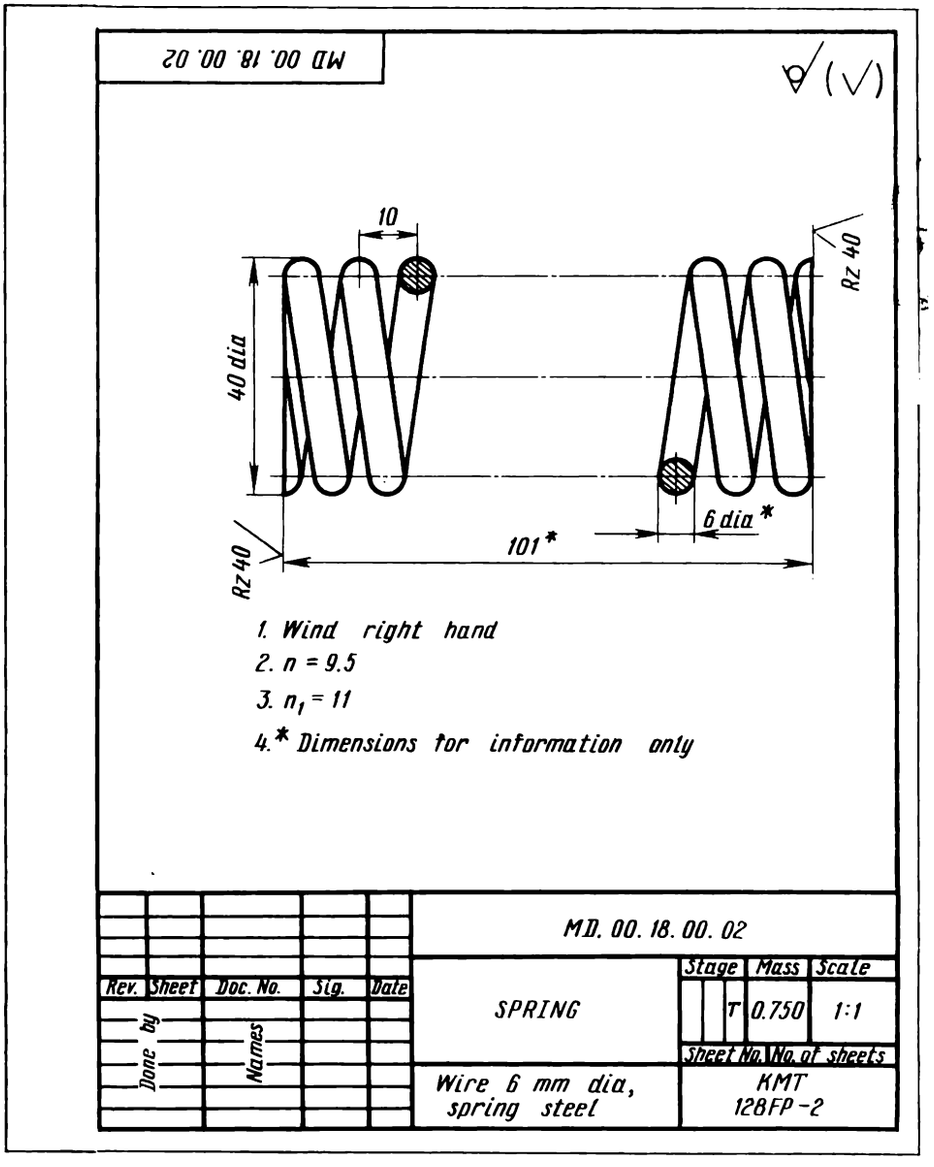


Fig. 441

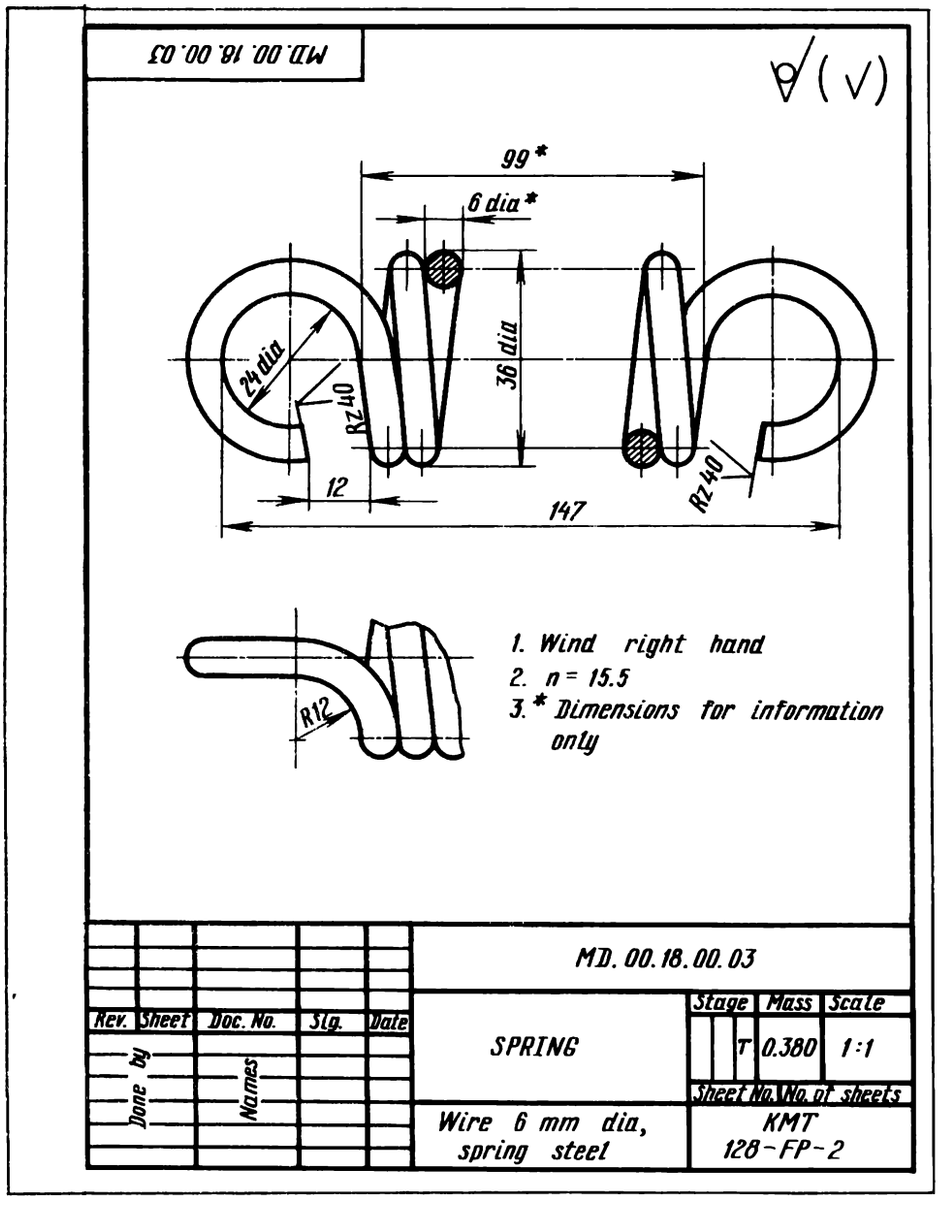


Fig. 442

1.5 closed (or squared) and ground coils. The construction of the end of such a spring is illustrated in Fig. 443*a*.

The outside diameter D, wire diameter d, pitch t and the number n of active coils are usually determined by calculations. The number of active coils is usually rounded off to the nearest value that is a multiple of 0.5. If it is assumed that the spring has 1.5 end coils, we can find:

(1) the free height: $H_0 = nt + d$;

(2) total number of coils: $n_1 = n + 1.5$.

If a helical compression spring is to have over four active coils, then one or two such coils is drawn at each end of the spring in addition to the end coils. The remaining coils are not shown, but centre lines are drawn through the centres of the coil cross sections over the whole length of the spring (Fig. 441).

Since certain dimensions and parameters of springs are interrelated (such as the pitch, number of coils, and length), certain dimensions are given on the drawings for information only.

The size of the stock is specified with the

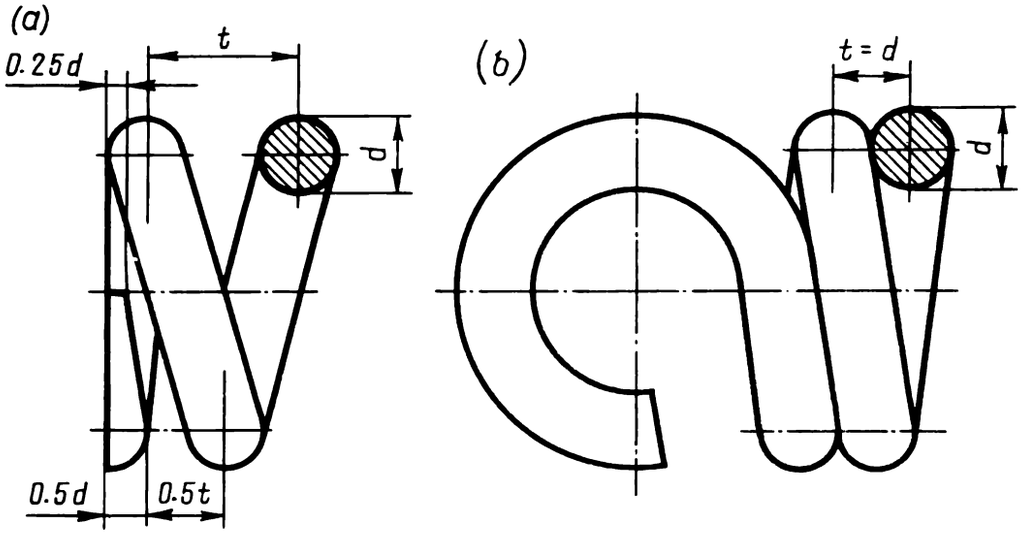


Fig. 443

material in the title block (for instance, wire 6 mm in diameter) and completely determines the shape and dimensions of the cross section of the spring coils. Consequently, these dimensions are not indicated in the drawing or only shown for information (see Figs. 441 and 442).

In contrast to compression springs, which have clearances between the coils in the free state (Fig. 441), tension springs are made without any clearance between the coils (Fig. 442), i.e., in the free state, their pitch t is equal to the wire diameter d.

The construction of the coils of a tension spring is shown in Fig. 443*b*. All the coils of the spring (except hooks or loops) are active coils.

The free length of a tension spring (without the hooks or loops) is

$$H_0 = d(n+1)$$

where n is the number of coils. For springs with loops of the kind shown in Figs. 442 and 443, the length between the loops in the free state is $H_0' = H_0 + 2(D-d)$, where D is the outside diameter of the spring and d is the wire diameter.

The inside radius of the loops is $R = \frac{D-2d}{2}$.

If the end loops are of the open type, the space or opening between the end of the wire and the nearest coil of the spring may be taken equal to $D/3$.

In drawings, all helical springs are shown coiled right hand, the hand of spring required being indicated in the specifications. These specifications also give the number n of active coils and, for compression springs, the total number of coils n_1.

The USSR drawing standard provides for certain spring parameters which, in many cases, are given in a definite sequence in the manufacturing specifications.

If requirements are specified as to the force that the spring is to develop, a test diagram is shown on the drawing. This diagram indicates the dependence of the load on the spring upon its deformation (or vice versa). The length of the wire required to form a spring is:

(1) for compression springs (Fig. 441)

$$L \cong n_1 \sqrt{[\pi(D-d)]^2 + t^2}$$

where the expression under the radical sign gives the length of a single coil;

(2) for tension springs (Fig. 442)

$$L \cong \pi(D-d)(n+2)$$

10. METHODS OF DUPLICATING DRAWINGS

Original drawings are the main technical documents according to which machine elements, units, sub-groups, groups and whole articles are made. They are usually duplicated for the machine operators, foremen, assemblymen, as well

as the quality control department and other people concerned. That is why original drawings should be made on a material permitting their duplication in as many copies as possible by printing and photographing. In most cases they are drawn on paper and then traced in ink on transparent tracing paper.

Recently, this time-consuming process of ink tracing has been replaced by making the original drawings in pencil directly on emulsion-coated tracing paper and lettering them by typing which saves time, paper, ink, and drawing instruments.

Questions

1. How many classes of surface roughness are established in the USSR? In what do they differ and what are the conventional symbols used to specify them in drawings?
2. What is the difference between a sketch and a working drawing?
3. What is meant by reading drawings?
4. How are springs depicted in drawings?
5. At what place on the drawing of a spring are the necessary data on the spring located?
6. Where do you write the manufacturing specifications in a detail drawing?

Exercise 68

Make a sketch (from a model) of a part having threaded holes and requiring a simple section.

Exercise 69

Make a sketch (from a model) of a part having webs and requiring a complex section.

Exercise 70

Make a working drawing of a part using the sketch mentioned in Exercise 69.

Exercise 71

Make a working drawing of a critical compression spring from a model.

CHAPTER 5

SEPARABLE AND PERMANENT JOINTS

All existing joints of machine parts may be divided into separable and permanent.

Some separable joints, namely threaded joints, have already been considered. Discussed below are some other separable joints frequently used in machine units designed for transmitting rotary motion, and also some permanent joints.

1. COTTER JOINTS

These are used when it is necessary to rapidly dismantle and reassemble detachable parts for adjusting clearances, as well as for tightening parts. The latter function is illustrated in Fig. 444*a*, where two journal bush inserts are drawn together by means of a gib and a flat cotter, and connected to the connecting rod end. A gib is a flat part having rectangular lugs which prevent it from falling out. The gib and cotter are brought in contact along an inclined plane whose gradient is within the range of 1/5 to 1/40. When the cotter is forced downwards by means of a stud and a nut, the yoke moves to the right and presses the bush inserts against each other. Assembly of a cotter joint is shown in Fig. 444*b*. First put the gib in place and screw in the stud, then insert the cotter and tighten it against the gib with the aid of a nut and a locknut (Fig. 444*c*).

2. KEYED JOINTS

Keyed joints may be fixed or movable, the former being more extensively used.

Keys are chiefly used to hold pulleys, gears (Fig. 445), couplings, clutches, chain sprockets, etc., on rotating shafts. They are also used to fasten cutting tools (for instance, milling cutters) to spindles.

Keyed joints are simple in design, compact and are easy to assemble and dismantle.

There are several standard types of keys: *prismatic* (Fig. 446*a*, *b*, *c*), *Woodruff* (Fig. 446*d*, *e*, *f*), *taper* (Fig. 446*g*, *h*, *i*), *tangent*, etc.

Prismatic keys are most widespread. In this

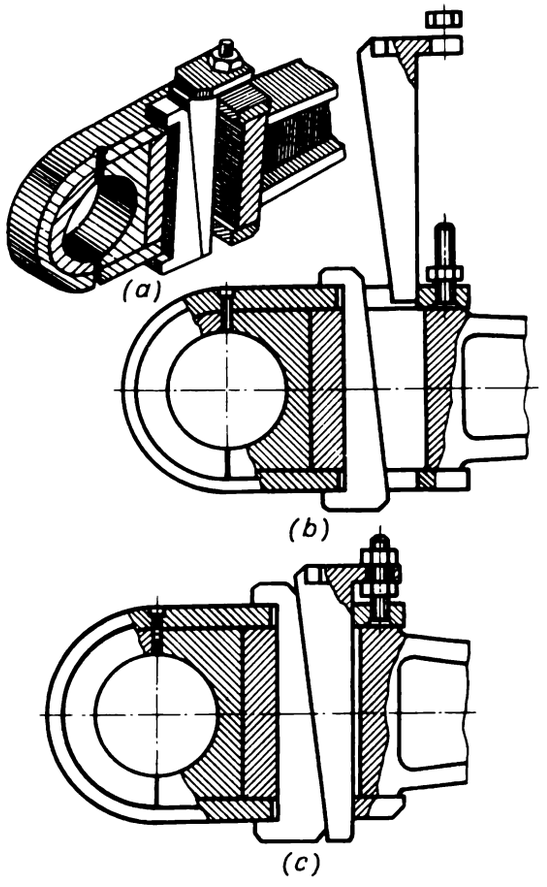


Fig. 444

case rotary motion is transmitted by means of the working faces of the key which is placed in a keyway provided in the shaft. There is a small radial clearance between the key and the keyway in the hub (see Fig. 446*c*). Prismatic keys may be square and rounded (Fig. 446*b*). If a part (say, a cluster gear) is to shift axially in operation, then a prismatic key is secured to the shaft by screws. Such a key is called a feather key.

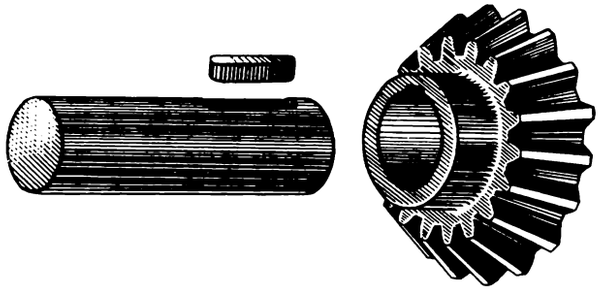


Fig. 445

Keys are usually provided with a threaded hole. When dismantling a keyed joint a screw is driven into this hole until its end thrusts against the bottom of the keyway and the key is readily removed.

In a fixed joint a prismatic key with rounded ends is fitted in a groove of the same shape and length, and is reliably held in it without fastening to the shaft.

Woodruff keys (Fig. 446*d*) are utilized in the automobile, tractor, and machine-tool industries.

A prismatic and a Woodruff key are represented in Fig. 446*c* and *f*, respectively. As is seen from the drawings, the keys are not cross-hatched on longitudinal sections, and radial clearances are shown.

Key sizes are standardized. The main dimensions of prismatic shafting keys are to be taken from the appropriate standard depending on the shaft diameter D (see Table 16).

Thus, for $D=32$ mm the table gives the following nominal dimensions for a standard prismatic key: width $b=10$ mm, height $h=8$ mm; the length of the key l depends on the length of the hub. In the given case $l=22$ to 90 mm. Its conventional designation is: *Key* $10\times 8\times 50$, where 50 is the length of the key in mm.

For the shaft diameter $D=20$ mm the following key dimensions are chosen: $b=6$ mm, $h=13$ mm, $d=32$ mm, $l=31.4$ mm. This key is conventionally designated as: *Woodruff key* 6×13.

Taper keys are available in different modifications: with rounded ends (loose, or sunk keys), square ends (driven keys), and also with a gib head (Fig. 446*h*).

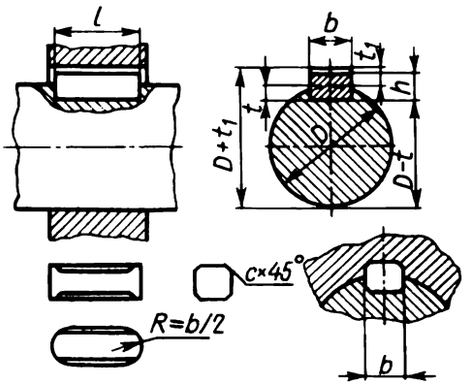
The working face of a taper key has a taper of 1/100. The hub groove should be provided with the same taper while the shaft keyway has no taper. The clearance between the side faces of a key and the groove should be shown on the drawing.

When assembling, a loose key is placed in the shaft groove and then the hub is mounted; whereas a driven key is driven into the keyway after the hub is mounted on the shaft.

Tangent keys transmit heavy loads at low speeds. A tangent key joint consists of two wedges with a taper of 1/100. The wedges are arranged so that their outside narrow faces remain parallel to each other, therefore the keyways in the shaft and the hub have no taper.

Table 16

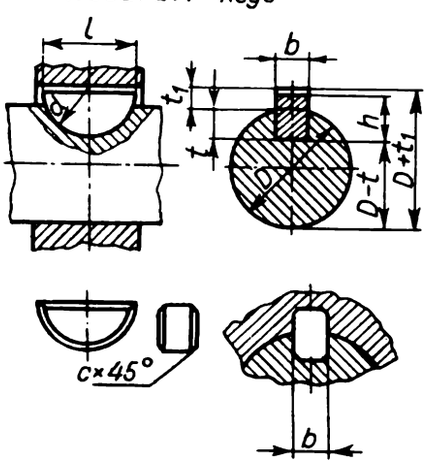
Prismatic keys



Dimensions in mm

Diameter of shaft *D*	Nominal size of key		Shaft *t*	Hub t_1	*l*	*c*
	b	*h*				
Over 18 to 24	6	6	3.5	2.6	14 to 55	
Over 24 to 30	8	7	4.0	3.1	18 to 70	
Over 30 to 36	10	8	4.5	3.6	22 to 90	0.3
Over 36 to 42	12	8	4.5	3.6	28 to 100	
Over 42 to 48	14	9	5.0	4.1	36 to 140	

Woodruff keys



Dimensions in mm

Diameter of shaft *D*	Nominal size of key				Shaft *t*	Hub t_1	*c*
	b	*h*	*d*	*l*			
Over 18 to 24	6	9	22	21.6	6.5	2.6	0.4
		10	25	24.5	7.5		
		11	28	27.3	8.5		
		13	32	31.4	10.5		
		15	38	37.1	12.5		

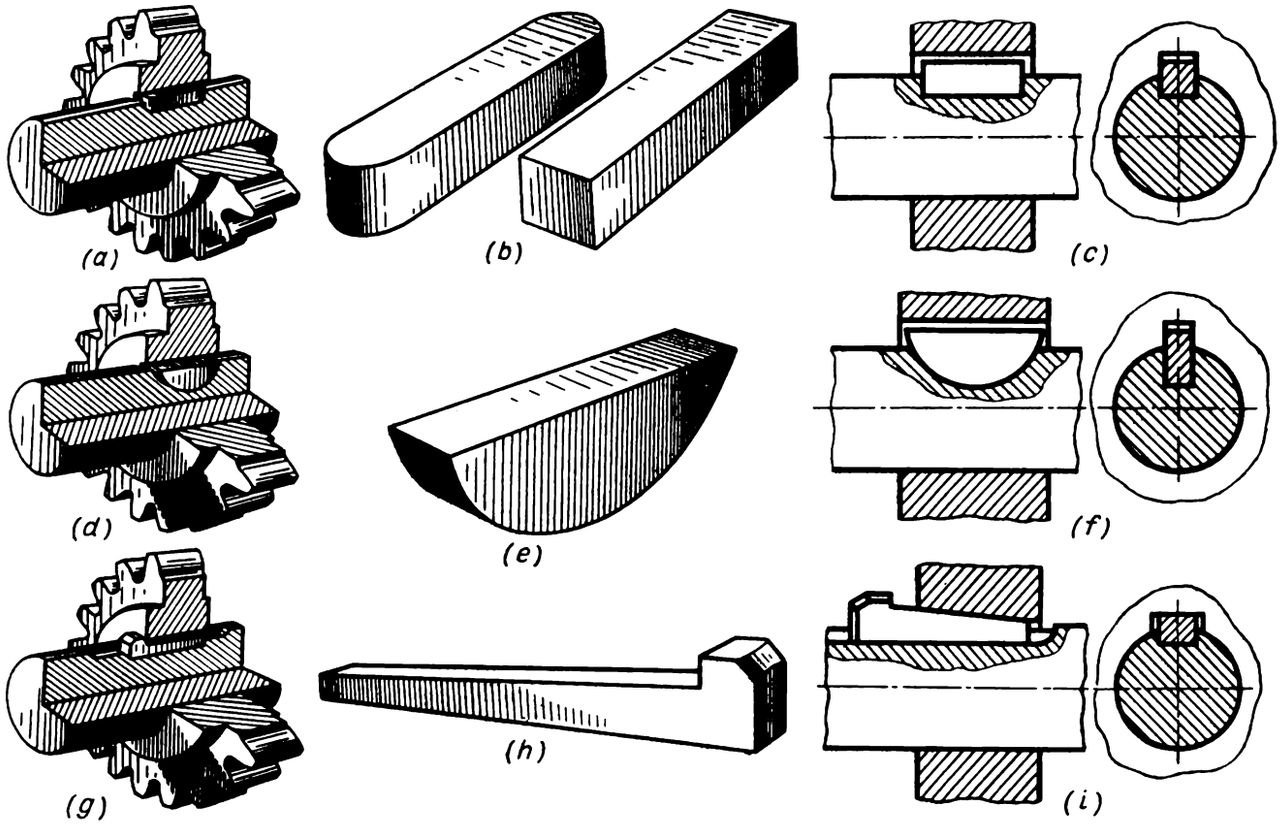


Fig. 446

A tangent key is accommodated in the seat so that its outside wide face is tangent to the shaft, while one of its narrow faces is arranged in the radial direction.

3. SPLINED JOINTS

A splined joint is formed by splines provided on the shaft and slots of the same profile in the hub (see Fig. 447*a*). As compared with a keyed joint a splined joint offers the following advantages: heavier loads are transmitted, better centring of hubs is obtained, the strength of the joint is increased.

The following spline profiles are used:

(1) *Parallel-side* (Fig. 447*b*). The corresponding fittings are divided into three series: light, medium, and heavy, differing in the height and number of splines. In this profile the side faces of the splines are parallel.

In a splined joint the hub can be located relative to the shaft in the following three ways:

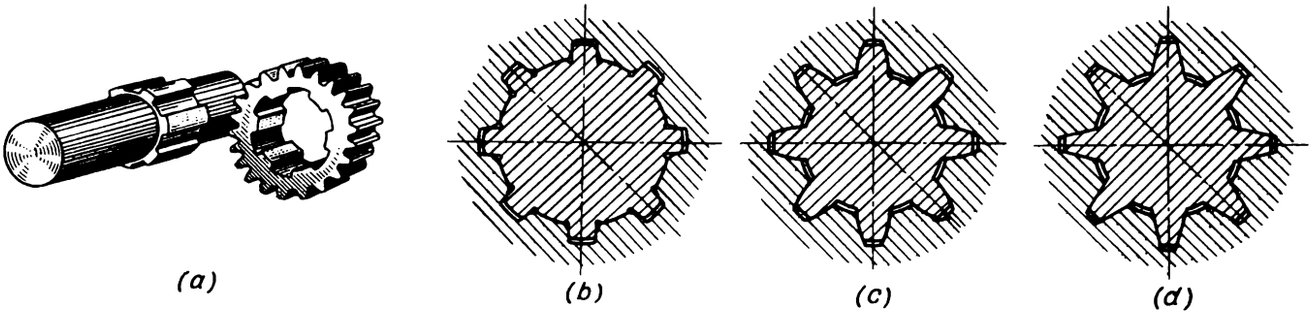


Fig. 447

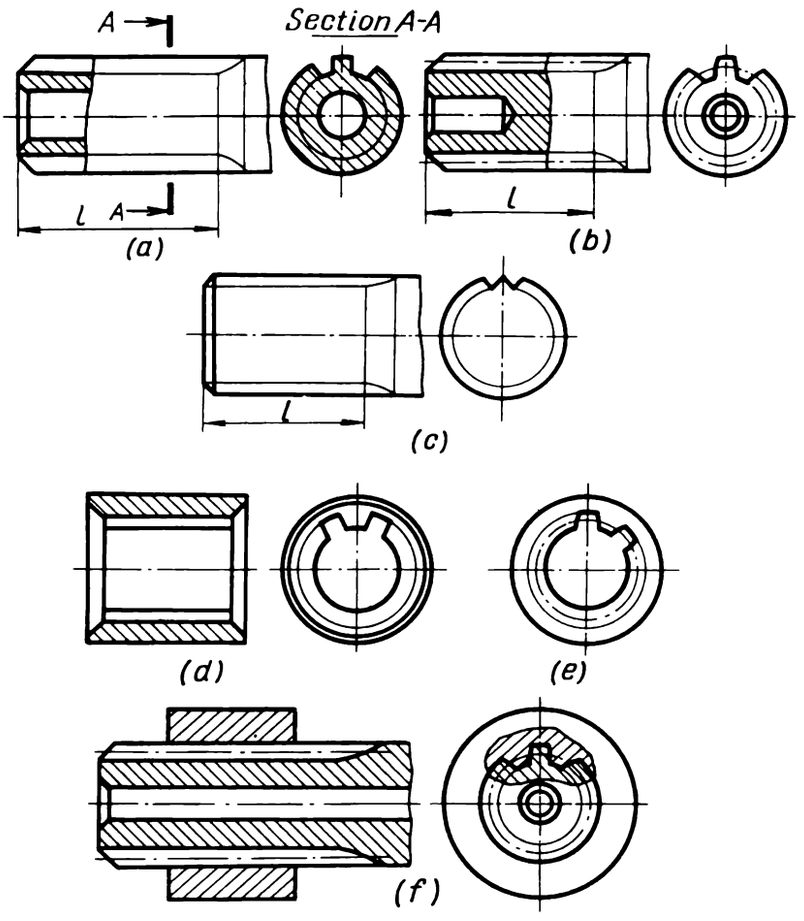


Fig. 448

according to the major diameter, according to the minor diameter, and according to side surfaces of the splines. The corners of shaft and hub splines are usually chamfered or rounded off.

(2) *Involute* (Fig. 447*c*). This profile is similar to that of gears. The involute profile splines are easier to machine and stronger than the parallel-side splines.

In this case the mating elements (the shaft and the hub) are located according to the side surfaces of the splines, or according to the major diameter.

(3) *Serrations* (Fig. 447*d*). Serrations are usually small. These joints are used in instruments with thin-walled hubs for transmitting light loads.

Splined joints are represented on drawings conventionally (see Fig. 448).

A working drawing of a splined shaft is given in Fig. 449. As is seen from the drawing, splines are shown conventionally: the circles and elements of spline surfaces are drawn in heavy continuous lines, the elements of the spaces in thin continuous lines; the elements of the spaces on the longitudinal section are drawn is heavy continuous lines. The dimension 56 mm in Fig. 449 indicates the length of full-profile splines (without the cutter radius).

Sections *A-A* and *B-B* show the spline profile.

Drawings of splined joints should supply the following information:

(a) the locating surfaces specified by one of the diameters *(D* or *d)* or by the spline side surface *b* (see Table 17);

(b) the main dimensions: number of teeth *z*, major diameter *D*, and minor diameter *d;*

(c) the fits designated in accordance with the locating diameter and the side surfaces of the splines.

The splined shaft drawn in Fig. 449 is conventionally designated as $D6\times28\times34XS_2X$ where *D* is the locating diameter; 6 — the number of teeth *(z);* 28 — the minor diameter

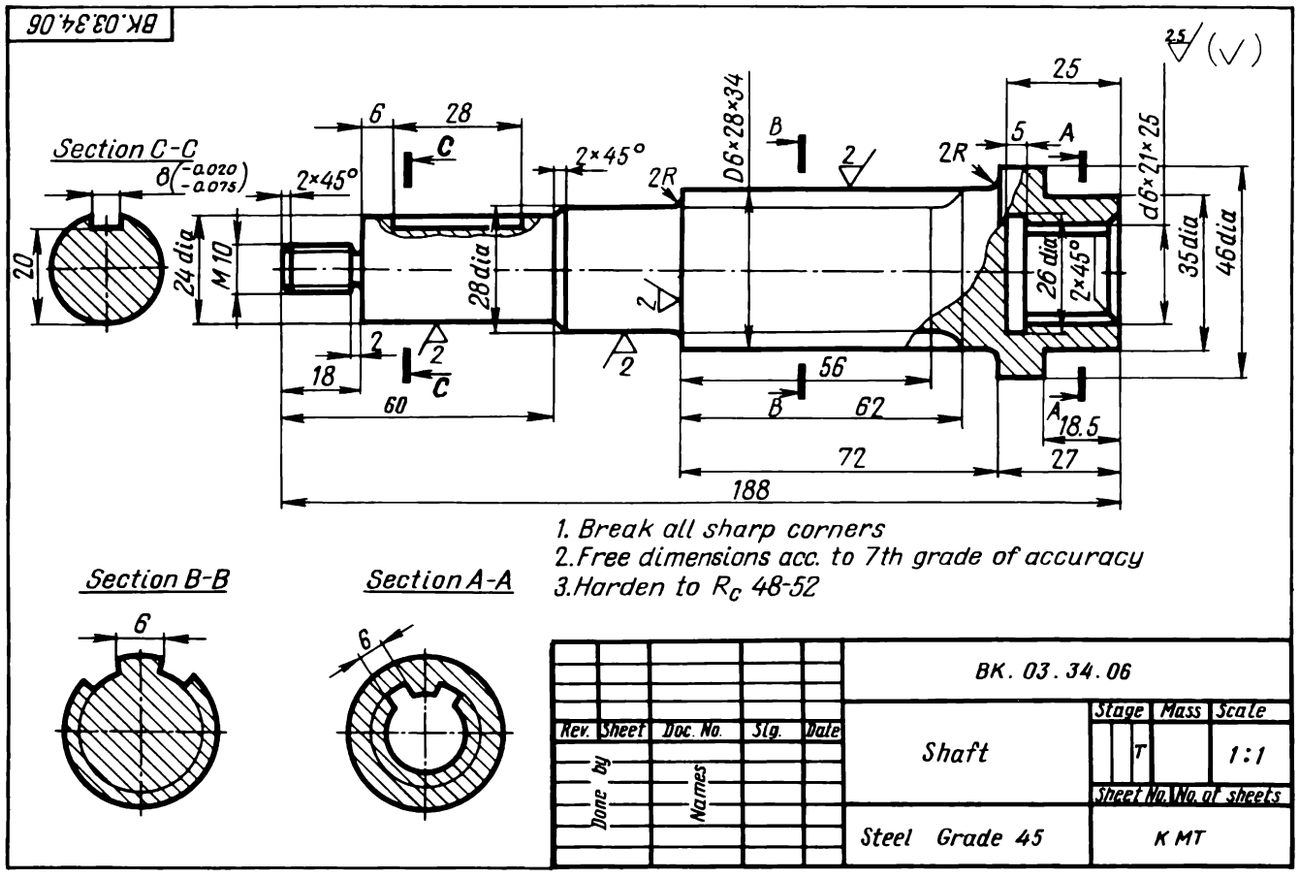
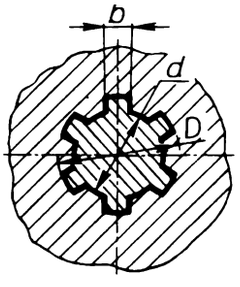


Fig. 449

Table 17

Specification of Parallel-side Spline Fittings
(from the USSR Standard)



Light-duty joint		Medium-duty joint		Heavy-duty joint	
$z \times d \times D$	b	$z \times d \times D$	b	$z \times d \times D$	b
8×46×50	9	6×28×34	7	10×46×56	7
8×52×58	10	8×32×38	6	16×52×60	5
8×56×62	10	8×36×42	7	16×56×65	5
8×62×68	12	8×42×48	8	16×62×72	6
10×72×78	12	8×46×54	9	16×72×82	7
10×82×88	12	8×52×60	10	20×82×92	6
10×92×98	14	8×56×65	10	20×92×102	7

in mm; 34 — the major diameter in mm; and XS_2X — the shaft spline fit.

A simplified designation on training drawings and sketches is: *D6×28×34.*

4. DOWEL PIN JOINTS

A dowel pin joint is another separable joint. Pins are also used for locating, checking, and safety purposes.

A dowel pin is a solid or hollow rod of cylindrical or taper shape. It is made of steel and machined on a lathe.

Figure 450*a* illustrates a practical application of a dowel pin which connects the cylindrical nut and the valve bonnet. The pin hole is drilled and reamed after the joint is assembled. Dowel pins are intended for correct alignment of pieces, for example, the casing and the cover of the reducing gear pictured in Fig. 450*b* and *c*. The pin hole is drilled after the casing and the cover are bolted together. Besides, dowel pins align the two parts for boring the bearing holes.

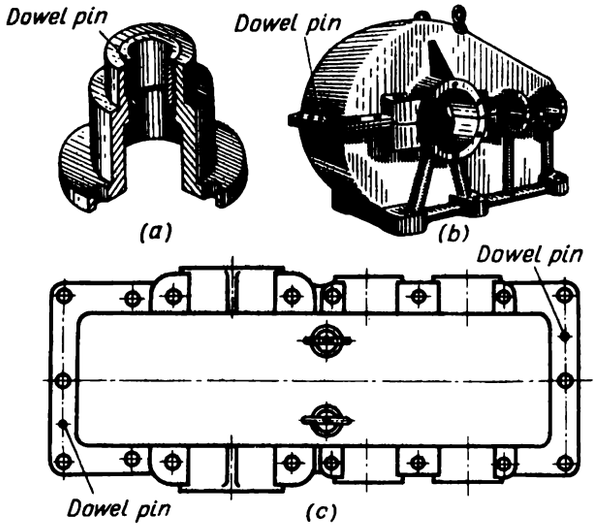


Fig. 450

Standard dowel pins may be cylindrical (as in Fig. 451*a*) and tapered (as in Fig. 451*b*). The taper of the latter pins $t=\frac{d_1-d}{l}=1/50$. Dowel pins are held in position by friction, since they are driven in tight. To increase reliability of the joint the pin end is sometimes riveted over. The tapered pin has the advantage that it may be inserted and removed many times without impairing the joint.

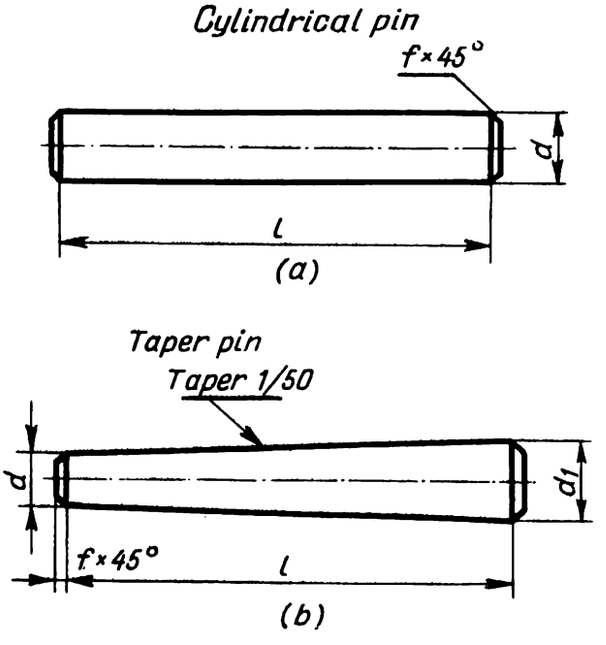


Fig. 451

An example of conventional designation of a cylindrical pin is: *Dowel pin 10×60 USSR Std.*

5. RIVETED JOINTS

Many metal structures consist of separate pieces held together by rivets. The purpose of rivets is to provide a permanent fastening between plates or rolled sections. Rivets are used in critical structures, such as aircraft, cranes, steam boilers, etc., and also where other joints cannot be employed. Fig. 452 illustrates the use of riveted joints in the bunker of a melting furnace.

Rivets are manufactured with a head at one end (Fig. 453*a*), the other head being formed after the rivet is driven. Holes for the rivets are drilled or punched slightly larger than the rivets so that they may be readily put in place. They are first heated (rivets of diameter up to 10 mm are not heated) and then inserted in the hole (Fig. 453*b*), after which the second head is formed by hammering with a pneumatic hammer or by pressure. The length of a rivet is chosen so as to allow just enough material to form the second head and fill the hole around the rivet.

Rivet heads may have various shapes, the button head being most common.

Rivets with countersunk heads are used where it is desirable to drive them flush. The countersunk head with a round top is stronger than that with a flat top and shows only slightly over the part surface.

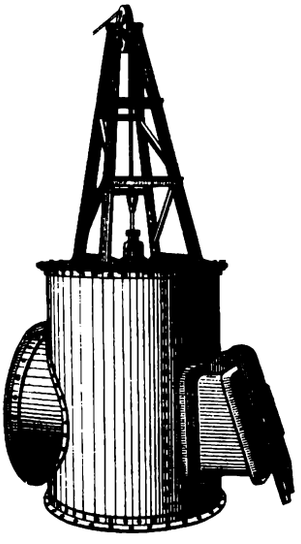


Fig. 452

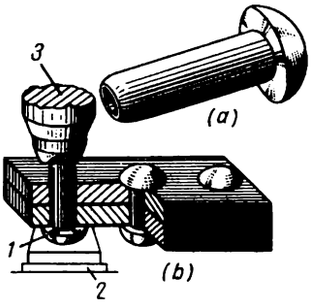
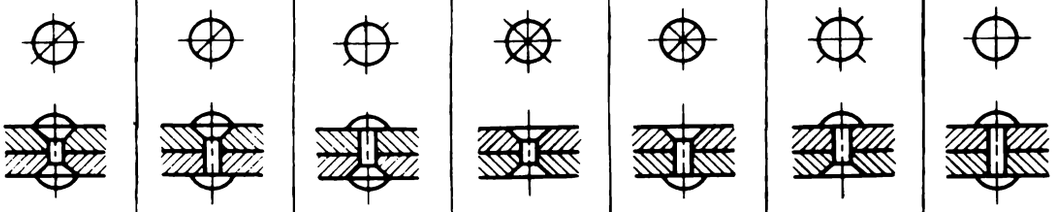


Fig. 453

Table 18

Rivet heads (shape and position)	Button	Countersunk (flat top)			Countersunk (round top)		
	both sides	near side (outside)	far side (inside)	both sides	near side (outside)	far side (inside)	both sides
Conventional representation							

The various shapes of rivet heads and their conventional representation on drawings are given in Table 18.

Hollow rivets are usually made of soft materials, such as copper, brass, aluminium and its alloys (Fig. 454*a*). Their heads may be of various shapes. These rivets are used in instruments and apparatus to join pieces made of soft materials: plastics, textiles, leather, cardboard, etc. In riveting very soft materials, washers should be used (see Fig. 454*b*).

To obtain tighter, water-proof joints explosive rivets are used. They are also used in aircraft work and where it is inconvenient or impossible to work on both sides of the plate. These are aluminium rivets that have been hollowed out at the end to allow space for the explosive charge (Fig. 455*a*). Such a rivet is inserted into the hole in a cold state and an electric heater is applied to its head (see Fig. 455*b*). At a temperature of 130 °C the charge explodes and the rivet is expanded to grip the plates as shown in Fig. 455*c*.

We distinguish between *lap joints* (Fig. 456*a*) and *butt joints* (Fig. 456*b*). Shown in Fig. 457 are two steel plates fastened by means of a

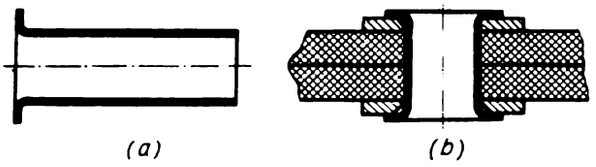


Fig. 454

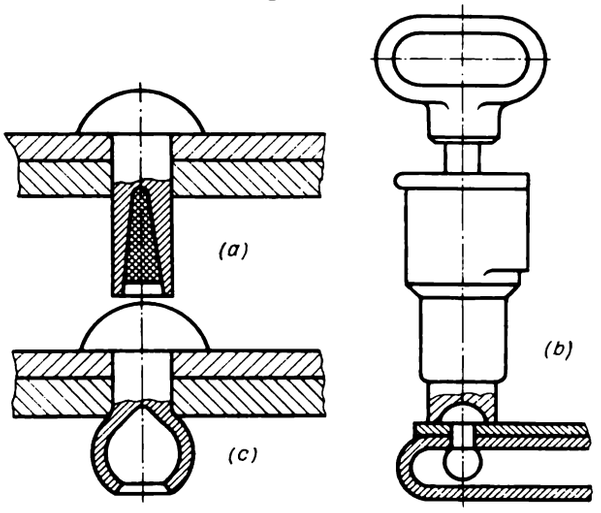


Fig. 455

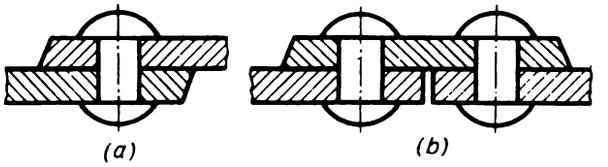


Fig. 456

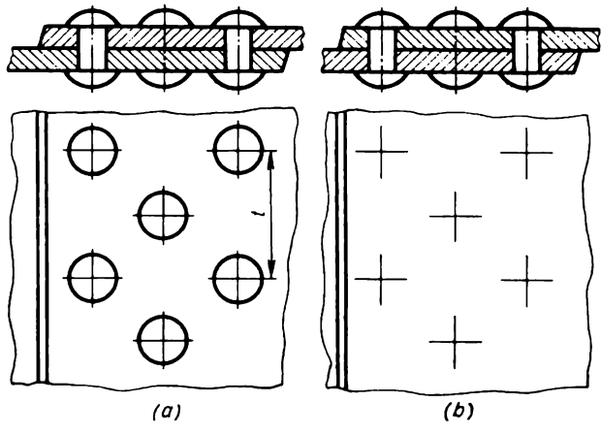


Fig. 457

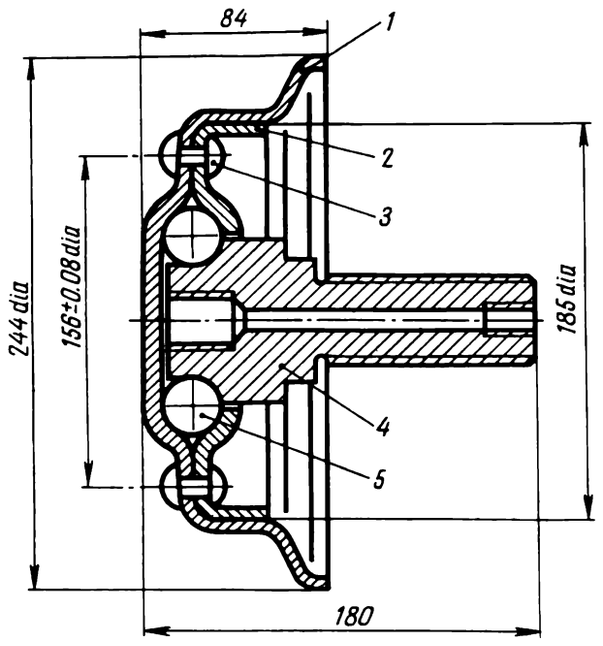


Fig. 458

triple, staggered, lap joint. The distance between the axes of two adjacent rivets of one row is called the *pitch* and designated by *t*. Rivets should be drawn according to the standard. They are sometimes shown on the drawing and sometimes omitted entirely. When shown they are represented by a circle (as in Fig. 457*a*), otherwise simply by centre lines (as in Fig. 457*b*). On a plane parallel to their axes rivets may be represented by a single centre line. Dimensions and other data should be indicated with the aid of leaders.

Shown in Fig. 458 is an assembly drawing of a riveted conveyor chain roller. As is seen from the drawing, the inside and outside rims of the roller are fastened by means of a single-row rivet joint of button-head rivets.

6. WELDING PROCESSES AND METHODS

(a) *General Information*

Welding is the most efficient method for permanent fastening of parts of a structure.

The two principal kinds of welding now generally used are (a) fusion welding and (b) pressure welding.

In fusion welding metals are welded together by melting them at the surfaces to be joined and allowing the metals to flow without the application of mechanical pressure.

In pressure welding two pieces of metal are united by heating and by applying pressure to bring about a plastic deformation at the joint. Some metals do not require heating.

Fusion welding may be effected by any one of the three processes:

(1) Gas welding, in which the heat is supplied by burning acetylene, hydrogen or some other suitable fuel gas. The gas under pressure is mixed with oxygen and ignited. This creates a very hot flame which can be regulated by adjusting the flow of the gas or the oxygen. This process is applicable to sheet metal, non-ferrous metals, and in repair jobs involving cast iron or aluminium.

A special welding rod is used to supply filler metal for the weld (see Fig. 459*a*).

(2) Arc welding, the most commonly used welding process, is based on the heat of the arc. Metallic arc welding, both its manual and automatic submerged-arc varieties (see Fig. 459*c*), is extremely versatile as it can be applied to a wide range of work size. Usually the parts to be welded are wired as one pole of the arc with the electrode held by the operator forming the other pole. Sometimes this is a carbon electrode, in which case the metal for the weld is supplied, by a welding rod held in the arc in a manner

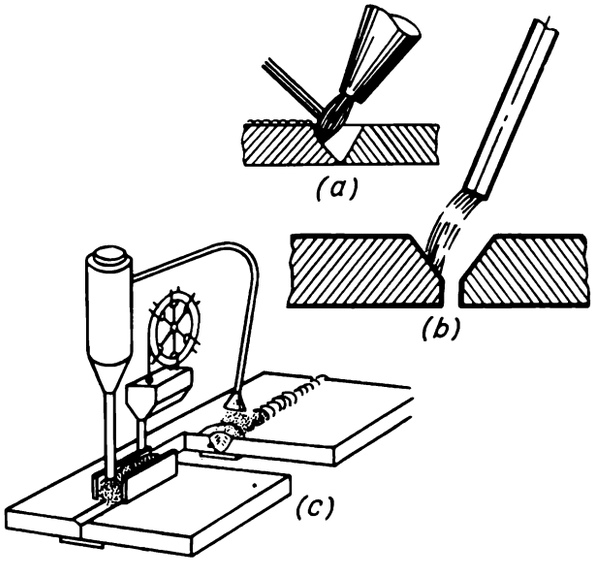


Fig. 459

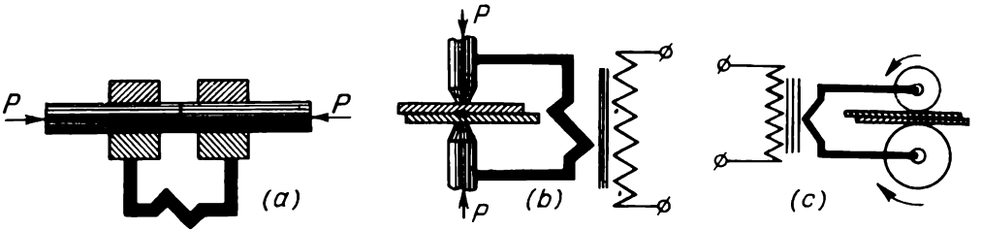


Fig. 460

similar to gas welding. More frequently the welding rod is used as the electrode so that it gradually melts away, thus supplying the metal for the weld (see Fig. 459*b*).

Wide use in made of shielded arc welding in which the arc and metal are protected from the air by argon, carbon dioxide, etc.

(3) Electroslag welding is a new welding process designed specifically for heavy plates. In this process the welding heat is generated by an electric current passing from the welding rod to the workpiece through a blanket of molten flux (slag).

This process compares favourably with arc welding as far as heavy-gauge metals are concerned.

Pressure welding processes are: resistance welding, gas-pressure welding, friction welding, etc.

Resistance welding is the main process in pressure welding, in which the fusion heat is generated at the joint by the resistance to the flow of an electric current passed directly through the workpiece. The heat reduces the metal to a plastic state; the pieces are then pressed together to complete the weld.

Resistance welding covers many processes of which the basic are butt welding, spot welding, and seam welding. Schematic diagrams illustrating the three methods are presented in Fig. 460*a*, *b* and *c*, respectively.

Welding enables highly automated processes to be introduced. Besides, many machine components are made by welding various elements together, thus making a built-up structure to replace a complicated casting of forging. Examples of such components are given in Figs. 461, 462, and 463, showing a press frame, reducing gear casing and bracket, respectively. Fig. 463 compares a cast bracket with a welded one of the same shape.

In addition to those mentioned above, many other welding techniques are employed (electroslag, gas-shielded, supersonic, laser, induction, etc.). With respect to the method used to accomplish the process, welding may be hand, semi-automatic or automatic. The standards of various countries stipulate designations of the welding

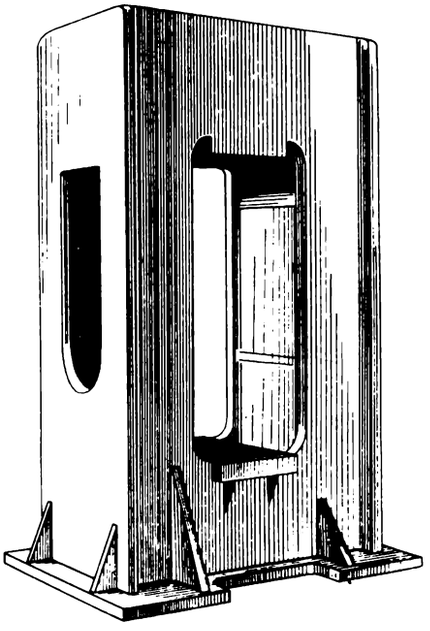


Fig. 461

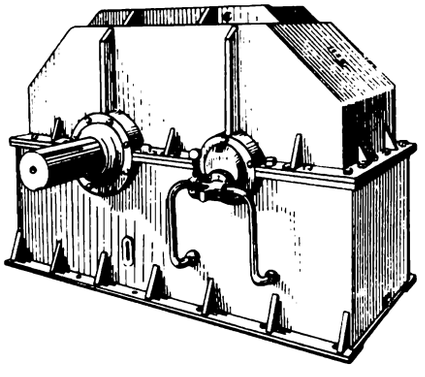


Fig. 462

technique to be used. For example: *S* — semiautomatic submerged arc welding; *A* — automatic submerged arc welding; *S-G* — semiautomatic gas-shielded welding with a fusible electrode; *A n-G* — automatic gas-shielded welding with a nonconsumable electrode; *A-G* — automatic gas-shielded welding with a fusible electrode; etc.

Data concerning the representation and designation of the most extensively employed fusion welds are given below.

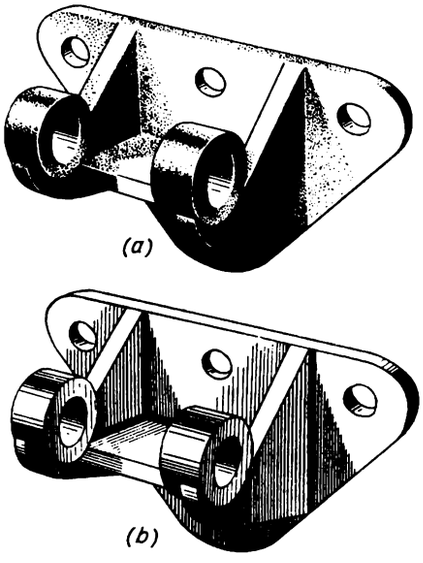


Fig. 463

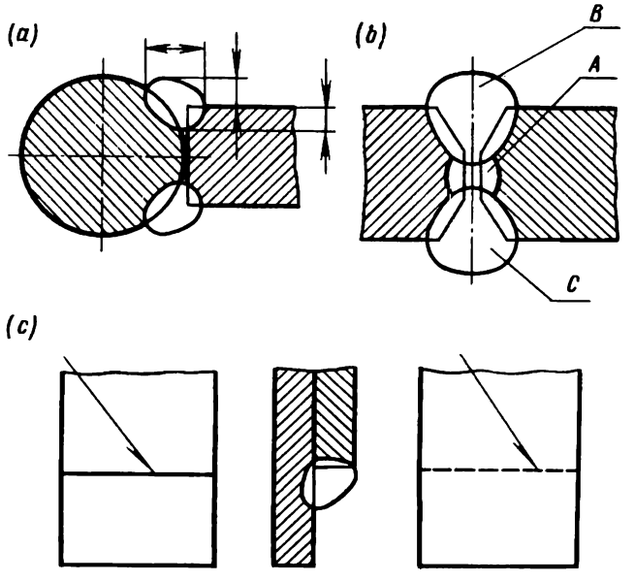


Fig. 464

(b) *Welding Symbols*

Systems for specifying weldments in drawings by means of symbols have been adopted in all industrial countries. Though there is some similarity in their general structure, these systems differ widely in details. The following discussion concerns the system adopted in the USSR.

If it is necessary to indicate the shape and dimensions of the weld (for example, a nonstandard weld), a cross section is shown in the drawing, as in Fig. 464. The outlines of the weld are shown by thick continuous lines and those of the elements of the edges within the weld, by thin continuous lines. The cross sections of the parts to be welded together are cross-hatched (section-lined) in different directions. If necessary, the elements of the weld may be dimensioned (Fig. 464*a*).

Welds may be single- or multiple-pass, depending upon the number of passes the welding arc makes along the seam. The outlines of the separate passes can be shown in the cross section of the weld, designating them by letters of the alphabet.

Regardless of the welding technique, a visible weld is shown by thick continuous lines, and a hidden weld, by short-dash lines. The welding symbols are indicated on a leader having a half arrowhead touching the weld.

(c) *Standard Welds*

As a rule, standard welds are employed in welding practice. Their dimensions are determined by the pertinent standards.

The weldments commonly dealt with in the drawing course are made up of carbon steel components joined together by a hand arc welding process. The type of weld is covered by a standard. A special standard covers welds of aluminium and aluminium alloys and another is for welding Viniplast (polyvinyl chloride or PVC) and polyethylene. A series of standards have been adopted that determine the types and elements of welded seams, as well as the welding methods.

Each standard weld has a *letter-and-number symbol* that completely specifies the elements of the weld. The *letters* in the symbol refer to the type of weld.

With respect to the positions of the welded

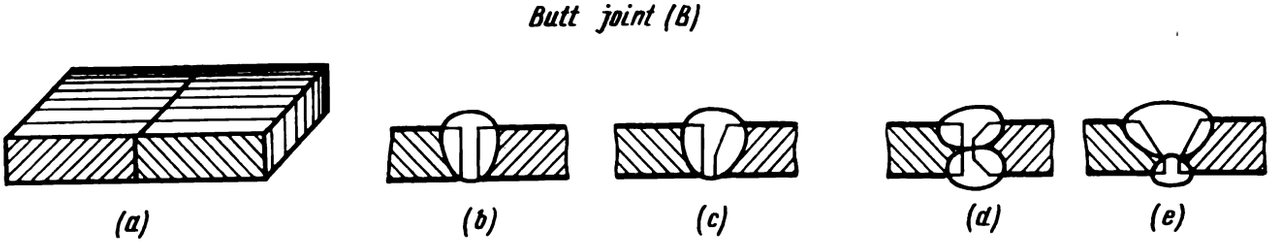


Fig. 465

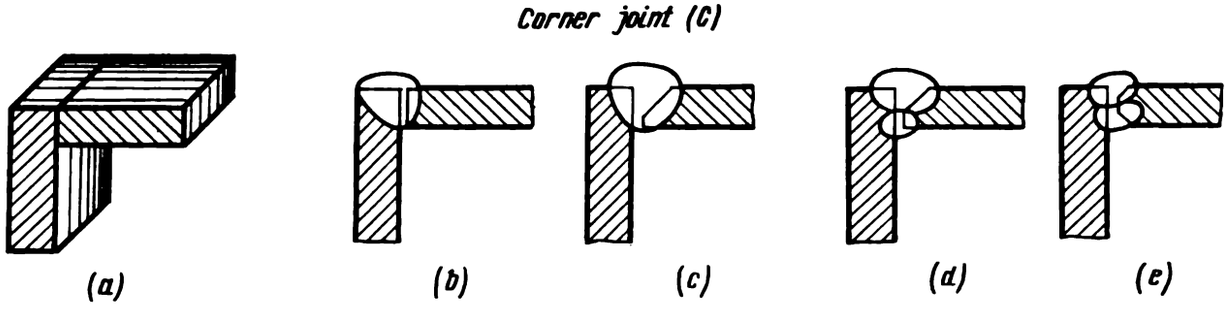


Fig. 466

components, welded joints can be classified into the following groups:

1. Butt joints *(B)*. The end faces of the parts are welded together (Fig. 465).

2. Corner joints *(C)*. The joined parts are at some angle to each other, and are welded together along the adjacent edges (Fig. 466).

3. Tee joints *(T)*. The end face of one part is welded to a side of the other (Fig. 467).

4. Lap joints *(L)*. The side surfaces of the welded parts partly overlap (Fig. 468).

The gap between the edges of the welded parts may vary from 0 to 5 mm. The edges of the welded parts may be prepared in different ways, depending upon the requirements for the weld. With respect to edge preparation, welds may be square (for the four types of joints); single-bevel (Fig. 465*c*, etc.); double-bevel (Fig.

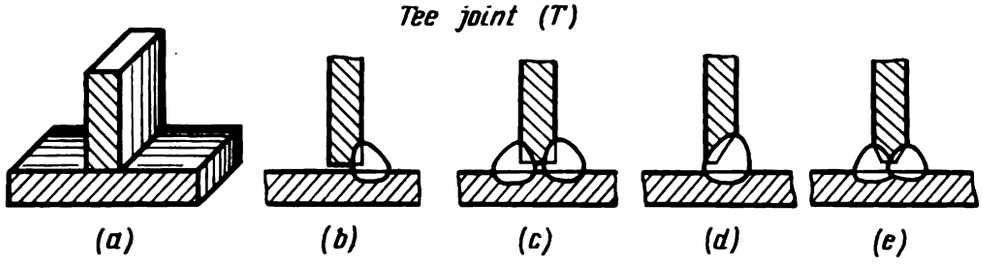


Fig. 467

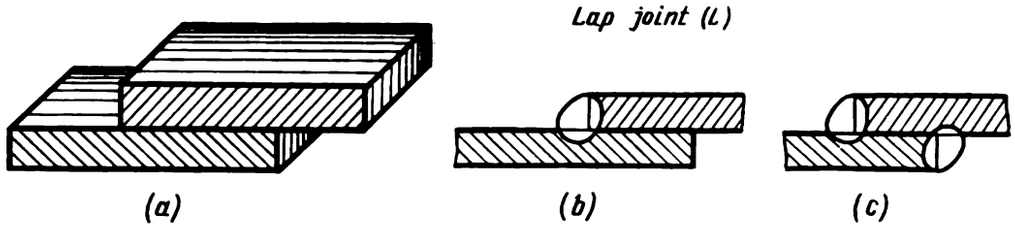


Fig. 468

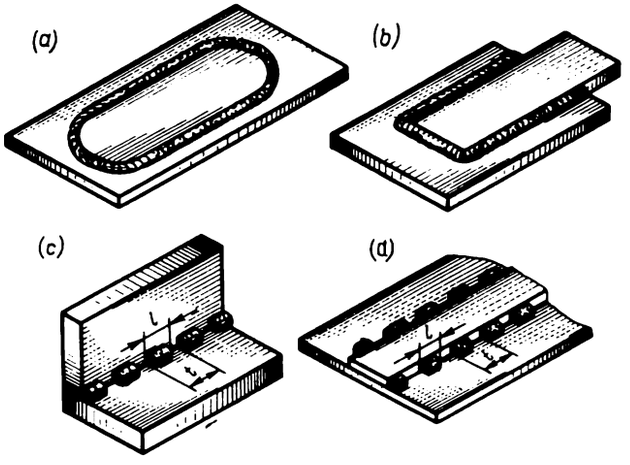


Fig. 469

465*d*, etc.); single-V (Fig. 465*e*, etc.) and double-V. The bevels may be either symmetrical or non-symmetrical; straight (V) or curvilinear (U and J).

Joints may be welded from one side (Fig. 465*c*, etc.) or from both sides (Fig. 465*d* and *e*, etc.). Welded joints may be either continuous (Fig. 469*a* and *b*) or intermittent (Fig. 469*c* and *d*). Specified for the latter are the length *l* of each increment and the pitch *t* of the increments. Double-sided intermittent welds may have the increments opposite one another (chain welds) or not opposite one another (staggered welds).

Welds may be made with reinforcement so that they are convex (Fig. 470*a*). The reinforcement of the weld is specified by dimension *g*. One of the dimensions specified for certain types of welds (some tee, lap and corner joints) is *K* (Fig. 470*a*), which is called the *leg length*.

The combination of all the design features of a standard weld is designated by a *number* which,

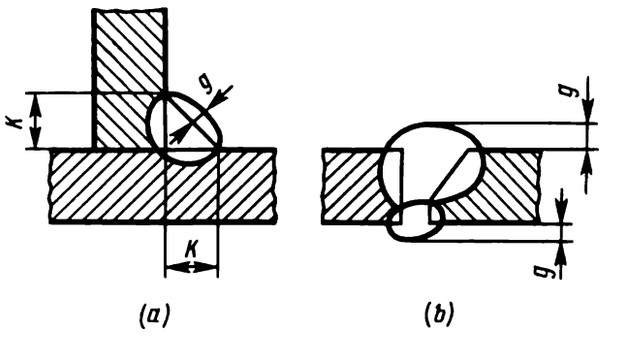


Fig. 470

together with the letter symbol of the weld, comprises the letter-and-number symbol of the weld according to the pertinent standard, for example: *B1*, *B2*, *B3*, ..., *C1*, *C2*, *C3*, ..., *T1*, *T2*, *T3*, ..., *L1*, *L2*, *L3*, ..., etc.

(d) *Designation of Standard Welds on Drawings*

In the representation of a weld, distinction is made between the face and back of the weld. The face of a joint welded from one side is the side on which the welding is done (Fig. 471). The face of a joint with a non-symmetrical edge preparation and welded from both sides is the side of the principal weld *A* (Fig. 471*b*). Either can be considered the face of a joint with a symmetrical edge preparation and welded from both sides (Fig. 471*c*). Obviously, the representation of a hidden weld is to be considered the back of the weld.

Each weld is specified by a designation which is indicated as shown in Fig. 471:

(a) above the reference line of the leader if it is pointing to the face of the weld (Fig. 471*c*);

(b) under the reference line of the leader if it is pointing to the back of the weld (Fig. 471*a* and *b*).

The USSR standard establishes auxiliary symbols which are included in the weld designation and indicate its features (Table 19).

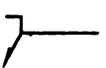
The structure of the designation of a standard weld (in the USSR) is shown in the diagram in Fig. 472. It is explained below for the simplest kinds of fusion welds:

1. Designation of the standard covering the type and design elements of the weld.
2. Letter-and-number symbol of the weld in accordance with this standard.
3. Conventional symbol of the welding technique according to the same standard (may be omitted).
4. For welds whose type is specified by the leg length (Fig. 470*a*), the following is indicated:
   (a) symbol 1 (Table 19),
   (b) leg length in mm.
5. Indicated for intermittent welds:
   (a) length of an increment in mm;
   (b) symbol 2 or 3 (Table 19);
   (c) pitch in mm.
6. Symbol 4 (Table 19).

If the weld is to be machined after welding the joint, the designation is followed by a symbol showing the permissible surface roughness of the weld.

Table 19

Auxiliary Symbols Specifying Welds and Included in Their Designation

Meaning of symbol	Symbol	Location of symbol with respect to reference line of leader pointing to weld	
		on face	on back
1. Symbol preceding leg length			
2. Chain intermittent weld. Line inclined at ≈60°			
3. Staggered intermittent weld			
4. Not-all-around weld. Used where position of weld is not clear from the drawing			
5. All-around weld. Diameter of symbol: 3 to 5 mm			
6. Field weld, i.e., weld made during erection or installation			

Notes: 1. Symbols are made with thin continuous lines.
2. The symbols should be of the same height as the figures in the weld designation.

Symbols 5 and 6 are placed at the intersection of the arrow and reference line of the leader (Table 19).

Only the parameters and symbols that specify the given weld are indicated. Since the conventional designation of a standard weld provides complete information about it, edge preparation, the gap between the parts and the outline of the weld are not shown in the cross sections of the joint, and the welded parts are cross-hatched in different directions (Fig. 473*a*).

Representations of welds with their conventional designations are given in Figs. 473 and 474. The meanings of the various elements of these designations are given below. As examples, designations are shown both on the face and back of the welds. It is obvious that in working drawings of welded joints, the designation is given only on one side (preferably the face).

The meanings of the elements of the designation given in Fig. 473 are:

(1) ⌐ — it is to be a field weld;

(2) *USSR Std.* — weld for joining parts of carbon steel by hand arc welding (the welding process is not indicated in the designation);

(3) *B18* — single-V butt weld with a backing bead. The dimensions of the edge bevels are specified in the standard which also establishes their shape (Fig. 473*b*);

(4) maximum permissible roughness of the weld surface: R_z20 on the face and R_z60 on the back of the weld.

The weld shown in Fig. 474*a* is characterized by the following data:

(1) ○ — an all-around weld is required;

(2) *USSR Std.* — weld for joining parts of aluminium;

(3) *T5* — staggered intermittent fillet tee weld

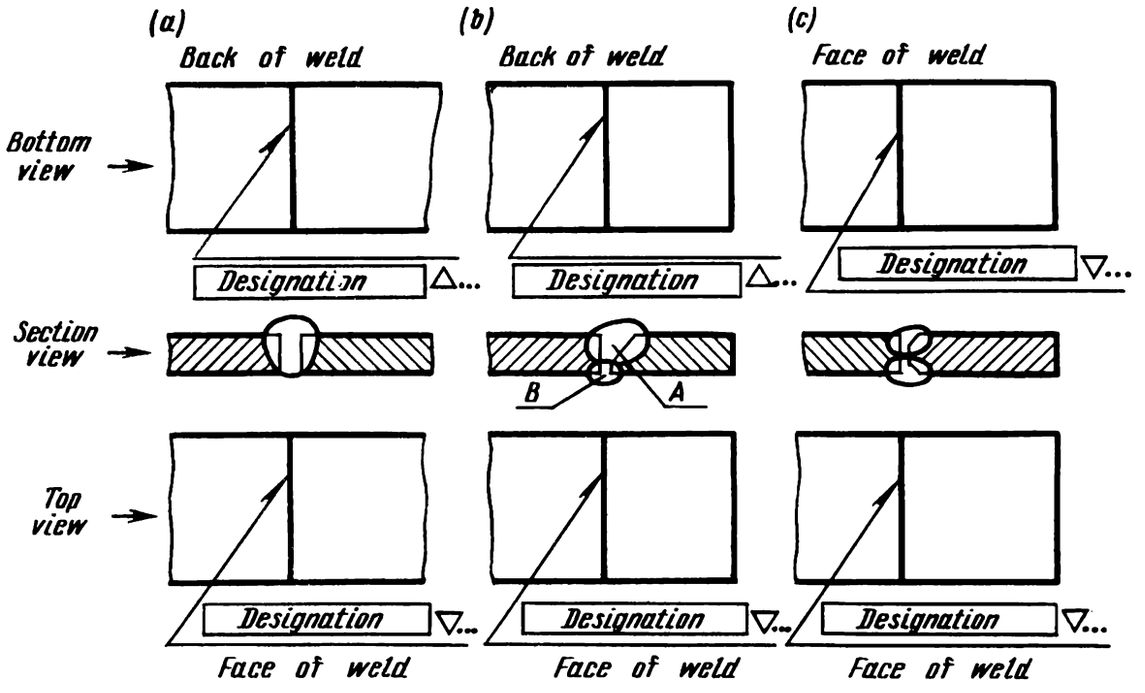


Fig. 471

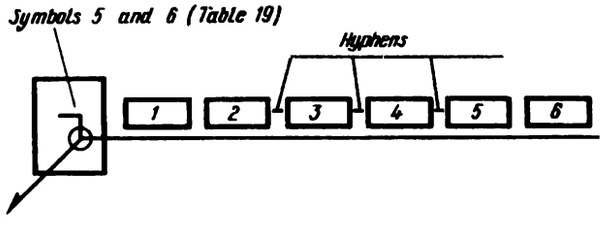
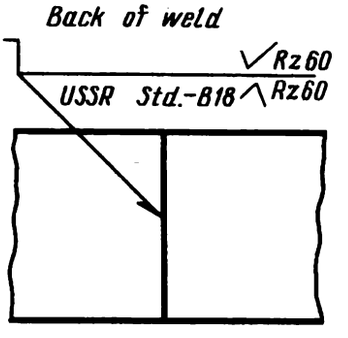


Fig. 472



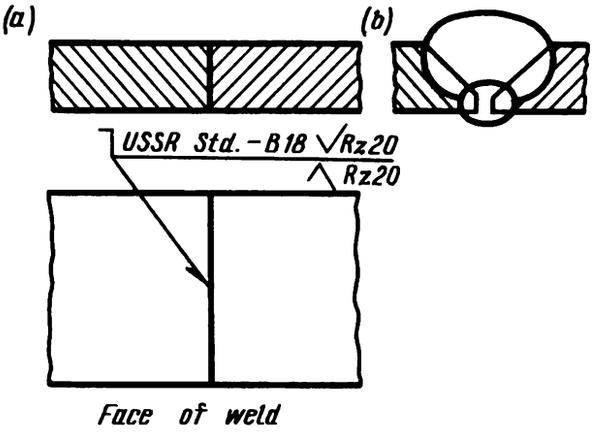


Fig. 473

(either side may be taken as the face of the weld);

(4) *H n-G* — hand gas-shielded welding with a nonconsumable electrode (may be omitted);

(5) ◺ *6* — leg length 6 mm;

(6) increment length — 50 mm;

(7) pitch of the increments — 100 mm.

The weld designation in Fig. 474*b* specifies the following:

(1) *USSR Std.* — weld for joining parts of aluminium;

(2) *L2* — intermittent fillet lap weld with square edges. Semiautomatic shielded-arc welding with a fusible electrode is used (the welding method is not indicated in the designation);

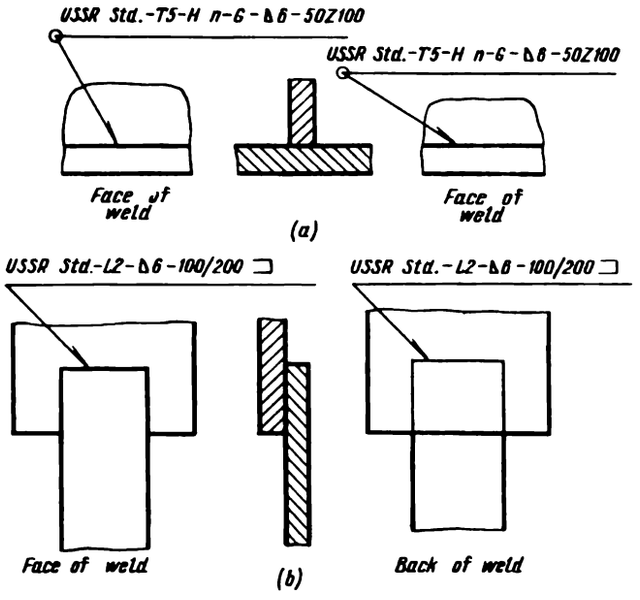


Fig. 474

(3) △ 6 — leg length 6 mm;
(4) increment length — 100 mm;
(5) pitch of the increments — 200 mm;
(6) ⊐ not-all-around weld.

The representation and designation of a weld for joining parts of polymers (plastics) is shown in Fig. 475. The specified data are:

(1) *USSR Std.* — weld for joining parts of Viniplast (PVC) or polyethylene;

(2) *B10* — double-bevel symmetrical butt weld. The standard establishes the shape of the edges (Fig. 475*b*). Either side can be the face of the weld.

(3) HGA — hot gas welding with an additive (may be omitted).

(e) *Simplified Weld Designation*

Sometimes all the welds may be the same in a weldment.

Welds are considered to be the same if:

(1) the types and sizes of their elements are the same in cross section;

(2) they must meet the same requirements;

(3) they have the same designation.

When several identical welds to are be depicted on a drawing, the designation is shown for only one of them, the remaining welds having only leaders with reference lines (Fig. 476).

All the identical welds are designated by one and the same ordinal number. This number is indicated:

(a) on the line near the arrowhead of the leader with the weld designation (the ordinal number may be preceded by a figure indicating the number of identical welds);

(b) above the reference line of the leaders drawn to all the other identical welds if the face of the weld is shown;

(c) under the reference line of the leaders drawn to all other identical welds if the back of the weld is shown (no such cases are shown in Fig. 476).

If all the welds in the drawing are identical and the same side of weld (face or back) is shown in all cases, the ordinal numbers may be omitted. Here all the welds, except the one carrying the designation, are specified by leaders without reference lines (Fig. 477).

On drawings of weldments having an axis of symmetry, it is permissible to draw leaders and give designations on only one of the symmetrical parts of the representation.

It is also permissible not to specify welds on drawings by leaders, giving instead all the necessary information on welding in the manufacturing specifications of the drawing. This information should unambiguously specify the location of the welds, the welding processes to be used, the types of welds, their elements and arrangement.

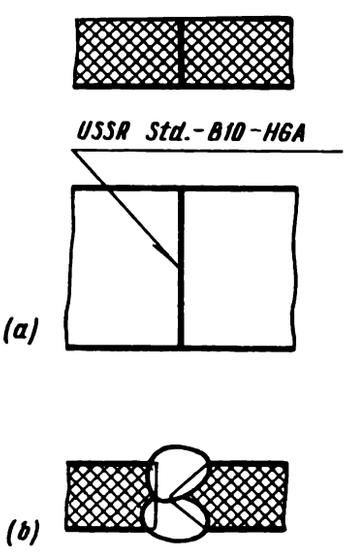


Fig. 475

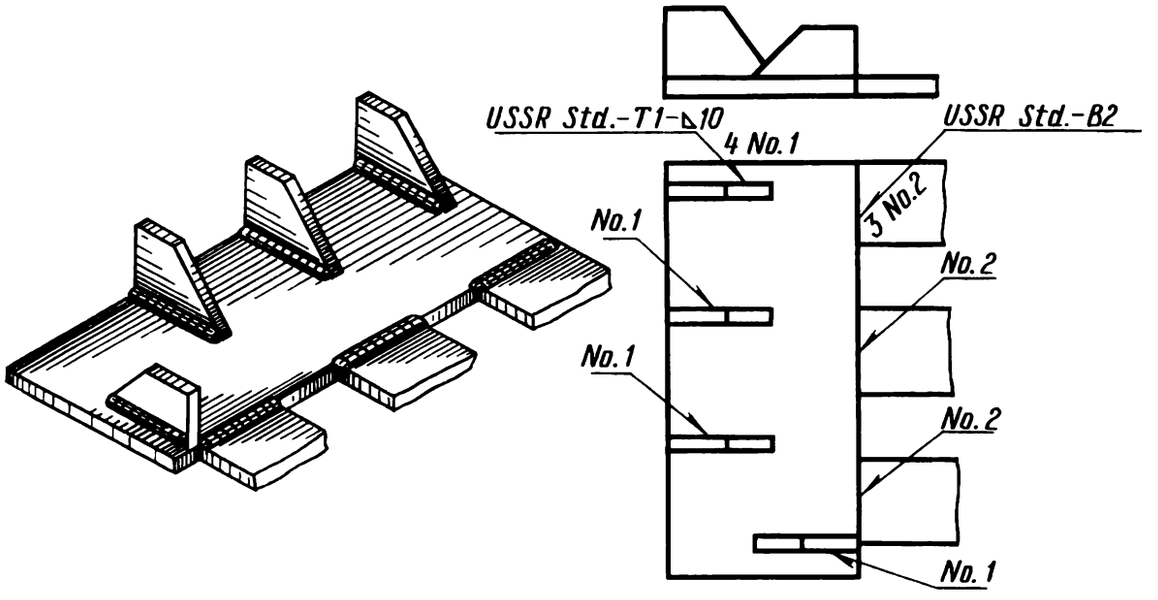


Fig. 476

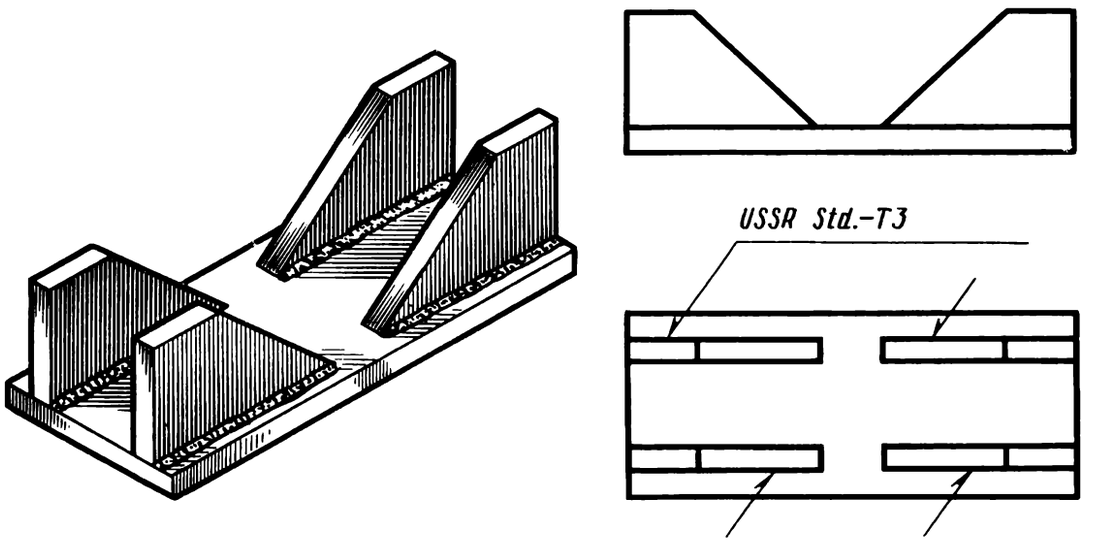


Fig. 477

(f) *Representation and Designation of Non-standard Welds*

In many cases use is made of non-standard welds (ones whose design dimensions are not covered by standards). In such cases, these dimensions are shown on a cross section of the weld.

Specified in the designations of the simplest non-standard fusion weld are the following:

1. For intermittent welds:
(a) increment length;
(b) symbol 2 or 3 (Table 19);
(c) pitch of the increments.

For a non-standard weld, the location of the designation with respect to the reference line of the leader, the use of symbols 5 and 6 (Table 19) and the designation of the surface roughness (if the weld is to be machined) are similar to those for standard welds.

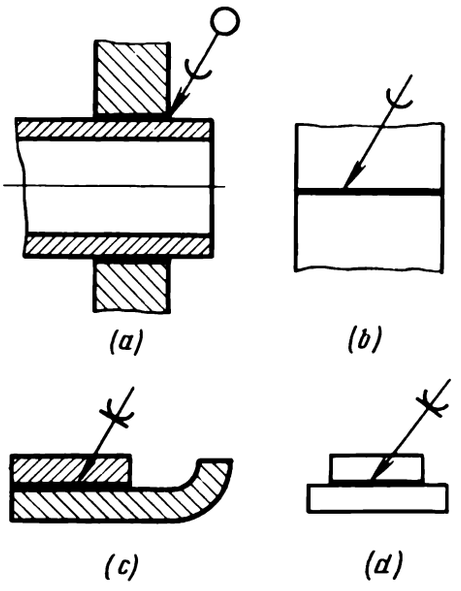


Fig. 478

The manufacturing specifications should indicate the method by which the non-standard weld is to be made.

(g) *Representation of Joints Obtained by Brazing, Soldering and Adhesive Bonding*

In brazing and soldering, in contrast to welding, the parts to be joined together are heated to the melting point of the brazing filler metal or solder, which is much lower than that of the base metals. The joint is obtained by filling the gap or clearance between the parts with molten filler metal (brazing) or solder (soldering).

Permanent joints obtained by brazing, soldering or adhesive bonding are represented in drawings according to a standard.

The filler metal, solder or glue in the section views (Fig. 478*a* and *c*) and in other views (Fig. 478*b* and *d*) is shown by lines twice as heavy as the thick continuous lines. Brazing and soldering (Fig. 478*a* and *b*) or adhesive bonding (Fig. 478*c* and *d*) are designated by conventional symbols drawn with thick continuous lines on leaders. When brazing, soldering or adhesive bonding is to be done around the perimeter of the joined parts, the leader should end in a circle 3 or 4 mm in diameter (Fig. 478*a*).

If necessary, the dimensions of the seam and the maximum permissible surface roughness can be specified for brazed or soldered joints. More detail on the conventional representation and designation of permanent joints obtained by brazing, soldering, and adhesive bonding (as well as industrial stitching and stapling) can be found in the pertinent standards.

According to a new CMEA standard on permanent joints (riveted, brazed, soldered, adhesive-bonded, industrially stitched or stapled):

1. The actual joint obtained by brazing, soldering or adhesive bonding is shown in section and other views by a very thick line. If the elements of the joint are blacked in in a section view, the joint itself is shown by a narrow clearance.

2. Brazing, soldering, and adhesive bonding are specified by symbols shown on leaders. The leader has an arrowhead when the joint itself is depicted or it has a point when the hidden surfaces of the joint are shown.

The brazing or soldering symbol is ⌣ .

The adhesive-bonding symbol is ⩙ .

3. Indicated on the reference line of the leader is the number of the item in the manufacturing specifications that indicates the grade of the filler metal, solder or glue.

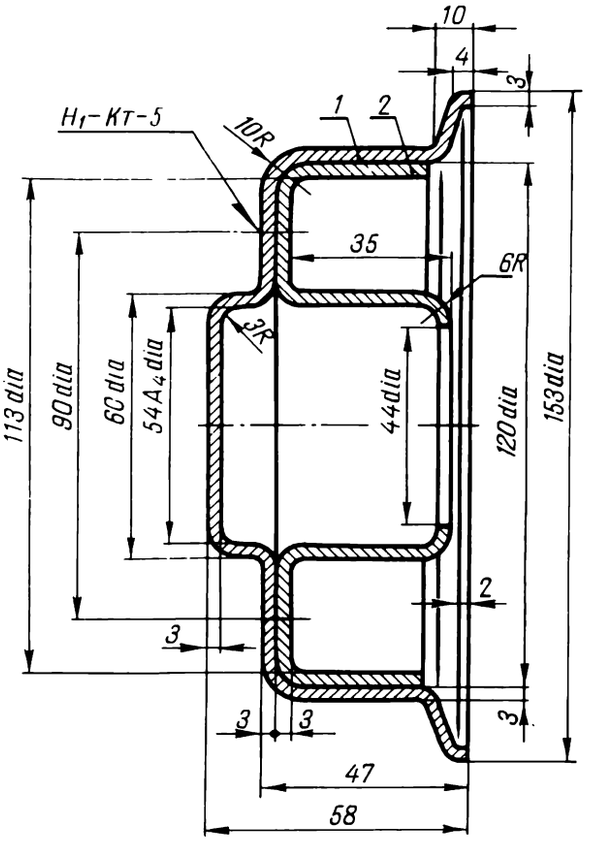


Fig. 479

7. EXAMPLE OF A WORKING DRAWING OF A WELDED JOINT

Figure 479 shows a working drawing of a conveyor bogie runner. The rim *1* is fastened to the roller *2* by means of a lap spot joint. The conventional designation of the welded seam is deciphered in the following way: Кт — resistance welding, H_1 — single-sided spot weld, 5 — spot diameter in mm.

Questions

1. When are cotter joints used?
2. How is the cotter taper calculated?
3. What are the main types of keys? Where are they used in mechanical engineering?
4. Decipher the conventional designation for a prismatic key: *Key 16×10×90.*
5. What are the advantages of a splined joint as compared with a keyed joint?
6. What are the standard splined profiles?
7. Decipher the conventional designation for a splined joint:

$$d8\times42\times48$$

8. How are splined joints represented on drawings?
9. What are the main types of dowel pin joints? Where are they used in mechanical engineering?
10. How is the pin taper calculated?
11. What types of rivet heads are used in mechanical engineering?
12. What types of riveted joints do you know?
13. What conventional designations are used for riveted joints?
14. What types of welding are used in mechanical engineering?
15. What types of welded joints do you know?
16. What conventional designations for welds are used on drawings?
17. How are the length and cross section of a weld designated?
18. What conventions are used in cross-hatching adjacent parts in welded joints?

Exercise 72

Make a sketch of a splined shaft (with sections) from a model using conventional designations.

Exercise 73

Make a sketch of a splined bush from a model.

Exercise 74

Make a sketch of a welded unit from a model (similar to Fig. 479) using the main conventional symbols for welds.

CHAPTER 6

GEARS AND GEARING

1. GENERAL

Rotary motion is transmitted from one shaft to another with the aid of different parts whose assembly is called a transmission.

There are various types of transmissions. With a large distance between the geometrical axes of two shafts a belt drive or a chain gear is used, whereas with small centre-to-centre distances use is usually made of friction drives and gearing.

A *belt drive* consists of a driving pulley, a driven pulley, and a taut belt (or several belts) which transmits power by means of friction force (Fig. 480*a*).

A *chain gear* consists of a driving sprocket, a driven sprocket and a chain which engages the sprockets (Fig. 480*b*).

A *friction drive* makes it possible to transmit rotary motion from the driving roller to the driven one by means of friction force. A friction drive between parallel shafts (Fig. 481*a*) consists of two rollers pressed against one another with some force. When the shaft axes intersect, bevel friction rollers are used (Fig. 481*b*). Friction drives are simple in design but have serious shortcomings: slipping of rollers, low power transmitted, necessity of a special device for pressing the rollers against one another, etc.,

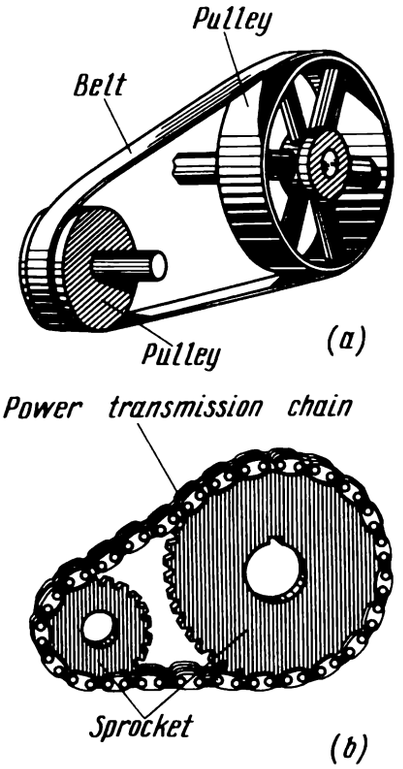


Fig. 480

therefore they are rarely used in mechanical engineering.

Gear drives are most widely used. Gear transmission between parallel shafts is accomplished by means of spur or helical gears (see Fig. 482*a*). If the shaft axes intersect, bevel gears are used (see Fig. 482*b*).

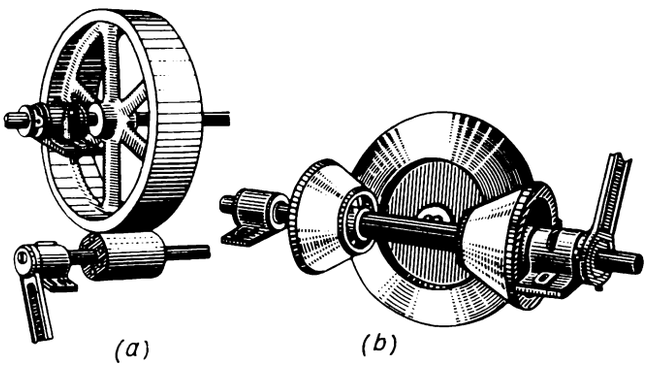


Fig. 481

A *worm drive* is used to transmit motion between crossing shafts. It consists of a worm, which is a screw with a trapezoidal thread, and a wheel (see Fig. 482*c*).

A *rack and pinion gear* serves to transform rotary into translational motion and consists of a spur or helical gear and a rack (see Fig. 482*d*).

2. GEAR MANUFACTURE

The teeth of gears can be cut in machine tools of various types by either a *forming* or a *generating* process. In the forming method, the tooth spaces are cut by some kind of form tool, called a *form relieved end mill* (Fig. 483*a*) or a *disk-type gear milling cutter* (Fig. 483*b*).

The generating process is more accurate than gear tooth milling. Generation is accomplished by making the rotating gear blank mesh with the teeth of a *rack-type gear-cutting tool*, as if

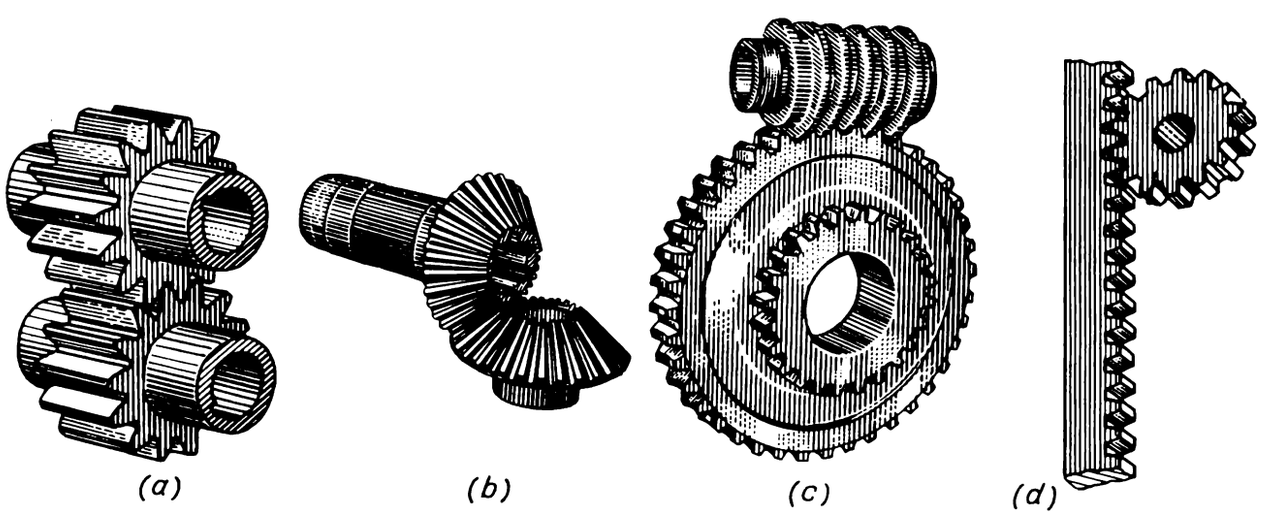


Fig. 482

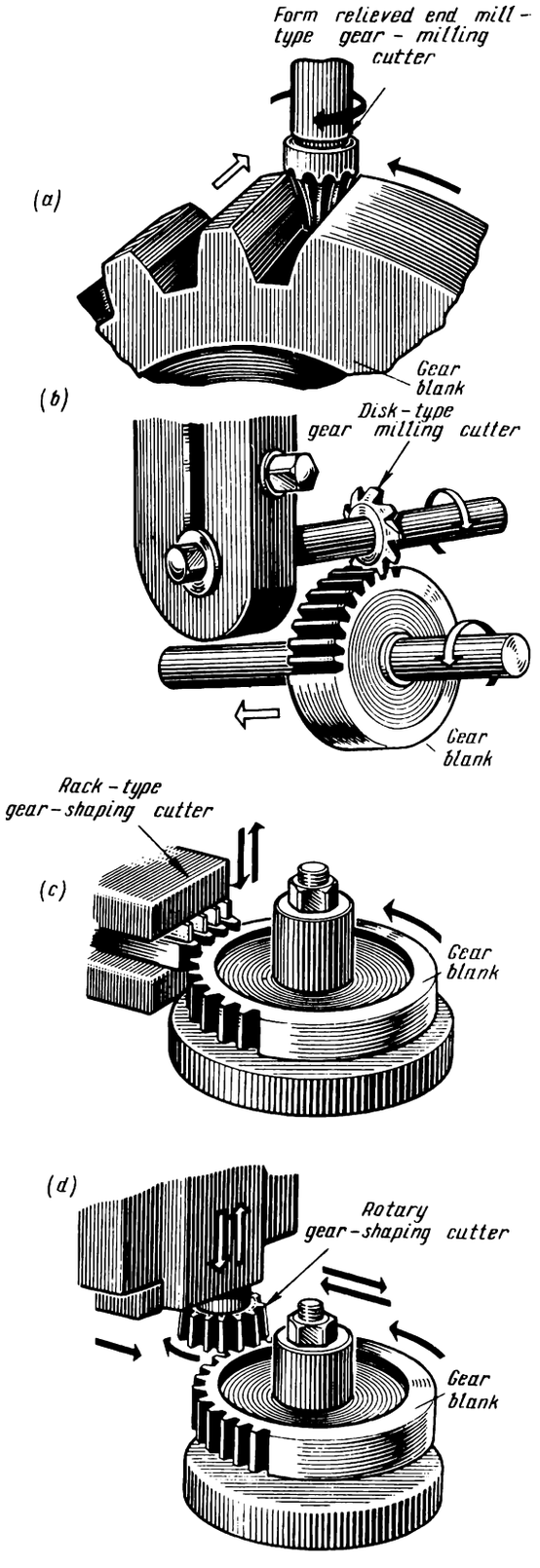


Fig. 483

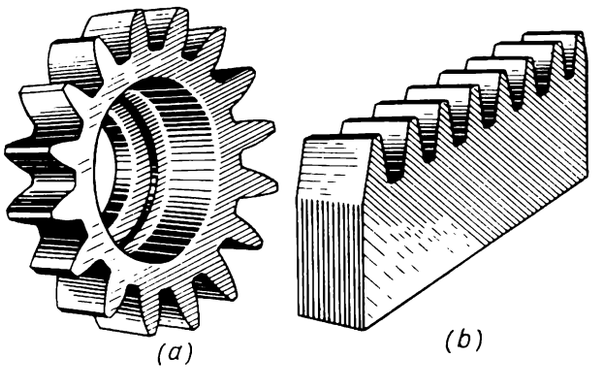


Fig. 484

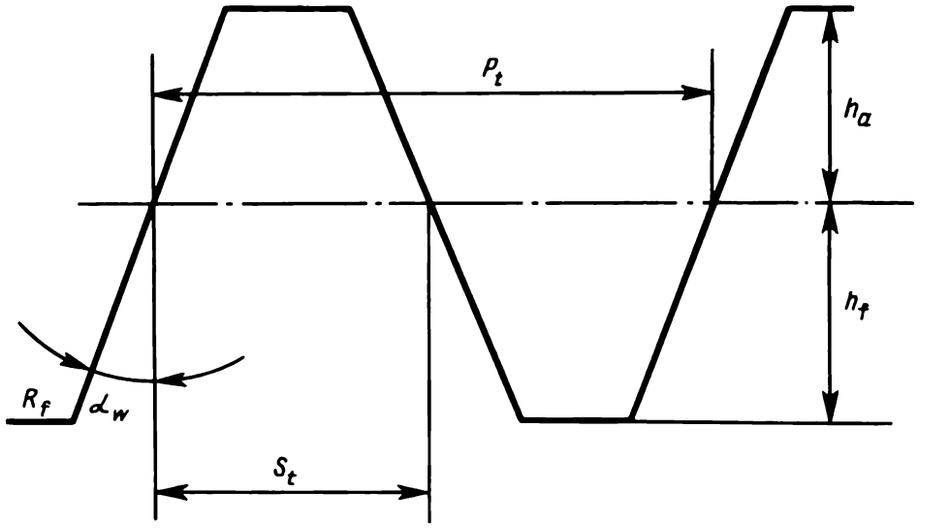
they were in engagement, in the corresponding gear-cutting machine. This cuts teeth of a definite profile on the blank (Fig. 483*c*). The teeth of the rack-type cutter, called the tool rack (Fig. 484*b*) have the shape and dimensions of the so-called *basic rack*, i.e., the outline of the teeth of a gear rack in a cross section normal to the direction of the teeth (Fig. 485). In this case, the profile of the teeth obtained on the blank will be an *involute* of a circle (or simply, involute). Besides the rack-type cutter, gears are cut by gear-shaping cutters which resemble pinions (toothed gears of comparatively small diameter). The gear-shaping process is shown in Fig. 483*d* and a gear-shaping cutter in Fig. 484*a*.

3. PARAMETERS OF TOOTHED GEARS

As mentioned above, a friction drive may consist of two plain rollers. The rollers are pressed together and when one rotates, the other will also rotate due to the force of friction developed between them (Fig. 481*a*). Such a drive may be subject to slippage between the rollers. Positive rotation, without slippage, can be transmitted by toothed gears (Fig. 486).

In gearing having the same speed ratio as a friction drive, the cylindrical surfaces of the rollers of the friction drive can be projected onto the gear drawing of the equivalent gears as *rolling circles* with diameters denoted by d_w (Fig. 486). The whole depth of the teeth is denoted by h (Fig. 487). Gears have a pitch surface which divides the teeth into two unequal parts. The height of the upper part is called the addendum, denoted by h_a, and that of the lower part, the dedendum, denoted by h_f (Fig. 487).

The side surface of the tooth (called the *face*



Basic rack form

Fig. 485

above the pitch surface and *flank* below this surface) meets the bottom of the tooth space with a curved line called the *fillet radius* and denoted by R_f (Fig. 487).

The toothed rim (Fig. 487) is bounded by the *addendum circle* of diameter d_a, and the *dedendum circle* of diameter d_f.

The conventional representation of gears on drawings is covered by the pertinent standard.

The addendum circles or the top land of the teeth are drawn with thick continuous lines; the dedendum circles or bottom land of the tooth spaces, with thin continuous lines. The pitch and rolling circles are shown by short chain (dot-and-dash) lines (see Fig. 487).

The spacing of the teeth and their dimensions are determined by the *circular pitch* $\hat{p}_t$, *circular tooth thickness* $\hat{s}_t$, and the *circular width* e_t of the tooth space. For any one module, these dimensions do not depend on either the number of teeth or the pitch diameter. They are related by the equation: $\hat{s}_t = \hat{e}_t = 0.5\hat{p}_t$.

The main parameter of the teeth of a spur, helical or any other type of toothed gear is the module m:

$$m = \frac{\hat{p}_t}{\pi} = \frac{d_w}{z}$$

The values of the module m are established by the pertinent standard, with preference being given to the first series (Table 20).

Of the various modules used for gears and wormgears: design, circular, normal, base circle pitch circle, and axial modules, only *one standard module* is to be used in the drawing course for each type of gear. This is the *design module*, denoted by m, for *spur gears;* the *large end module* m_e on the back cone for *straight bevel gears;* the *face module* m_t for *wormgears;* the *axial module* m_x for *worms* ($m_t = m_x$); and the *normal module* m_n for *helical gears.*

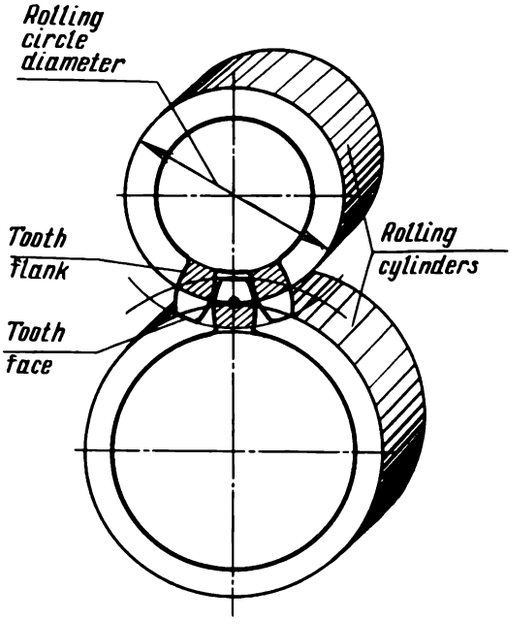


Fig. 486

Table 20

Modules (in mm) Used in Toothed Gearing

1st series	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	16	20
2nd series	1.125	1.375	1.75	2.25	2.75	3.5	4.5	5.5	7	9	11	14	18	22

In countries using a system of measurement based on the inch (Great Britain, USA, etc.), the basic parameter of gearing is the *pitch* of the gear tooth and not the module as in metric gearing.

All the elements of gearing depend upon the pitch, which is expressed as *diametral pitch* P_d or *circular pitch* p (formerly *DP* and *CP*). The diametral pitch $P_d=\frac{z}{d}$ is the number of teeth on gear per inch of its pitch diameter d. It is evident from the above equation that the diametral pitch is a reciprocal of the module when they are expressed in the same units of measurement: $P_d=\frac{1}{m}$, because the module $m=\frac{d}{z}$. Since the diametral pitch is expressed in inches, to find the equivalent module, the inches must be converted into millimetres.

The circular pitch p is the length of the arc of the pitch circle which measures one tooth interval (tooth and tooth space).

The tooth of a gear with $P_d=1\ 1/4''$, $p=2.5133''$ and $z=14$ is shown full size in Fig. 488.

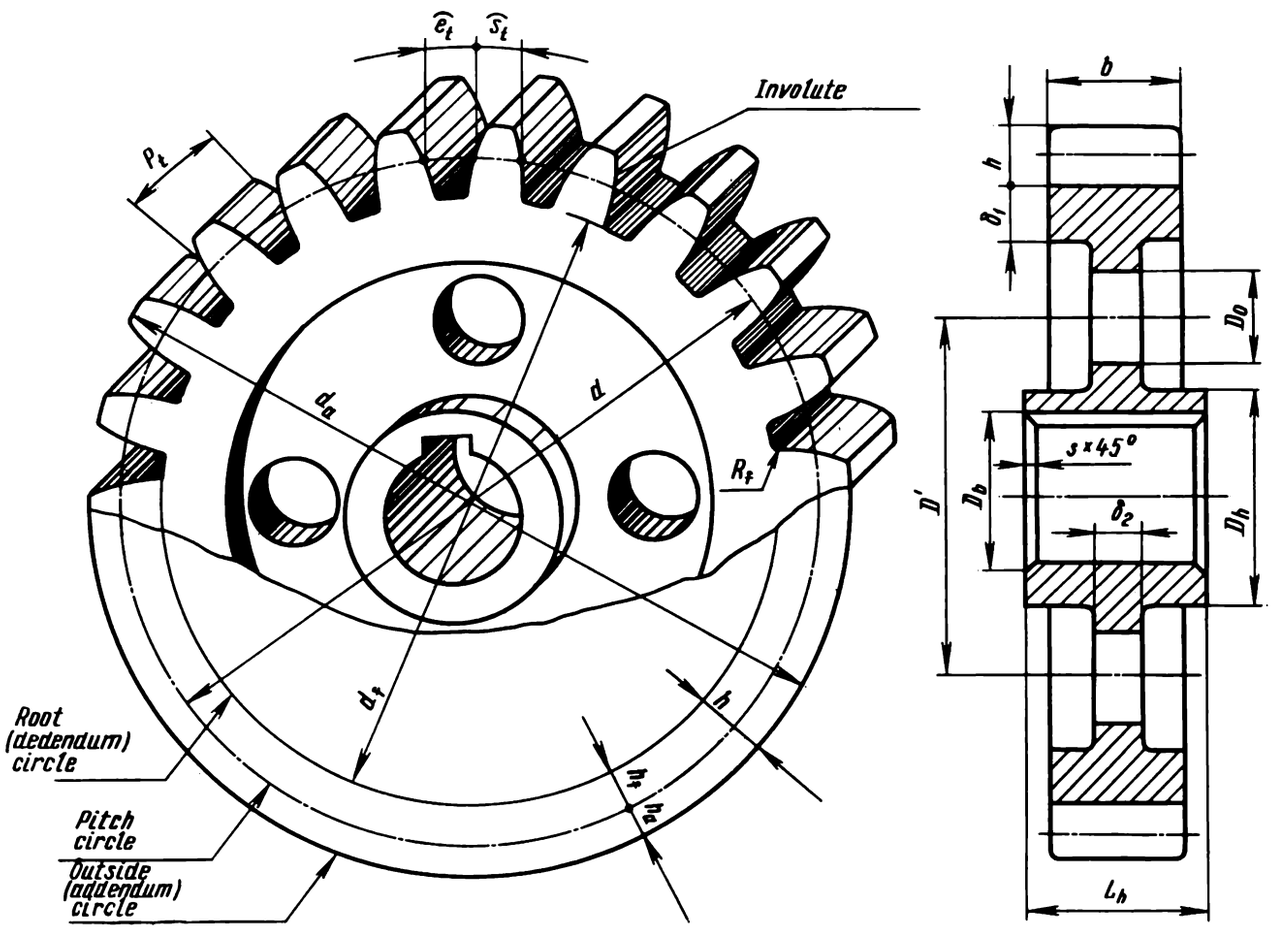


Fig. 487

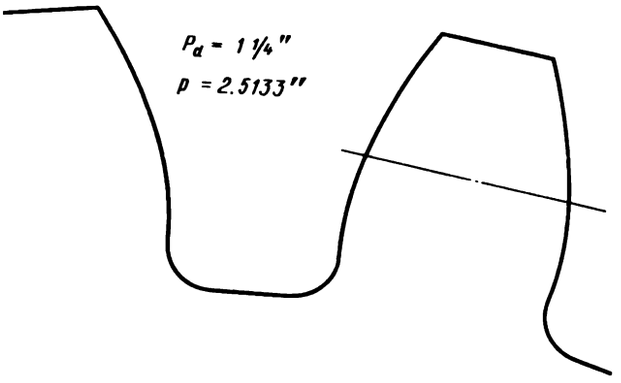


Fig. 488

Here: $d=\frac{z}{P_d}=\frac{14}{1.25}=11.2''$ is the pitch diameter, and the module $m=\frac{1}{P_d}=\frac{1}{1.25}=0.8''=20.32$ mm.

The circular pitch p in mm should equal the metric circular pitch $\widehat{p}_t$. Thus, $p=2.5133''=63.8$ mm and $\widehat{p}_t=\pi m=3.14\times 20.32=63.8$ mm.

Another concept in toothed gearing is the rolling circle. Let us consider a pair of toothed gears in engagement (Fig. 489*a*) and imagine that the gear teeth gradually diminish, changing proportionally in height and thickness (Fig. 489*b*), while the speeds of the gears (angular velocity) in revolutions per minute (abbreviated: rpm) and the distance between centres remain constant.

When the teeth have become infinitely small, the gears turn into plain cylinders (rollers) which have the same speeds as the gears, provided there is no slipping between them (Fig. 489*c*). These are called rolling cylinders and are projected onto the plane of the drawing as rolling circles whose diameter is denoted by d_w.

In standard involute gearing (in which $h_a=m$ and $h_f=1.25m$), the pitch and rolling circles coincide, i.e., $d=d_w$.

Correction is widely used in involute gearing to improve the strength and wear resistance of the gear teeth, especially for gears with a small number of teeth.

In cutting gears with a small number of teeth (for instance, $z=6$, 8, 10 or 12) by a generating method, the tooth profile at the flank is not an involute and has a small radius of curvature. This leads to rapid *wear* of the tooth. This effect, due to interference between the gear-cutting tool and the gear, is called *undercutting*, and the tooth thickness at the dedendum circle of *undercut teeth* is appreciably less than that of normal teeth.

The undercutting and wear of gear teeth can be reduced by displacing the gear-cutting (generating) tool (rack-type or gear-shaping cutter) a certain distance in the radial direction with respect to the centre of the gear blank. This displacement is $a=xm$ (Fig. 490).

This process is called the *basic rack displacement*, or *correction*, of toothed gearing.

Correction is extensively applied in up-to-date involute gearing design. The two main forms of correction are *height* and *angular* correction, the former being simpler and more widely used. Since the pitch and rolling circles do not coincide in corrected gearing, the addendum of the pinion (the smaller one of a pair of mating gears) is greater in magnitude than the module, and the

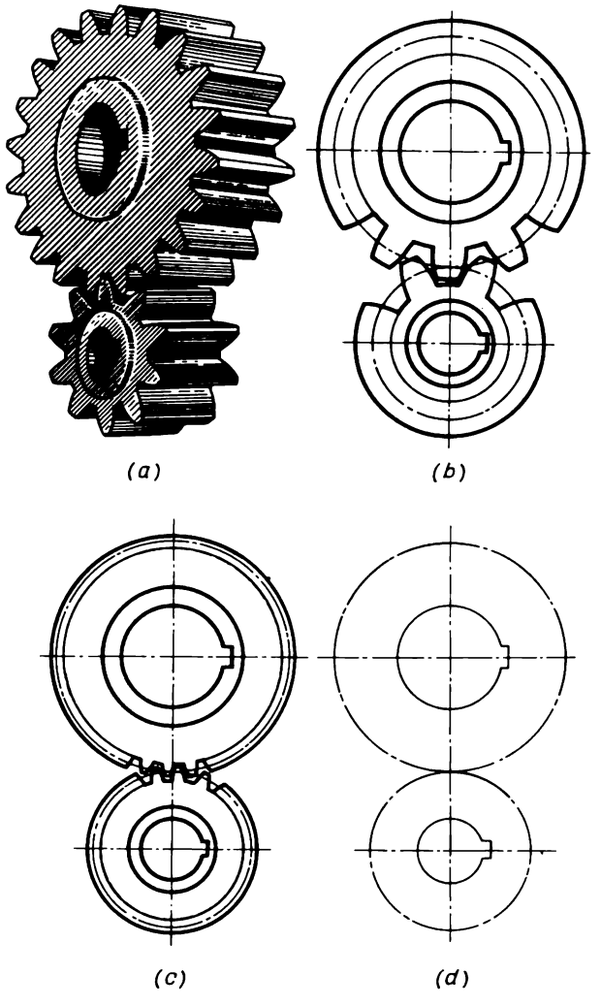
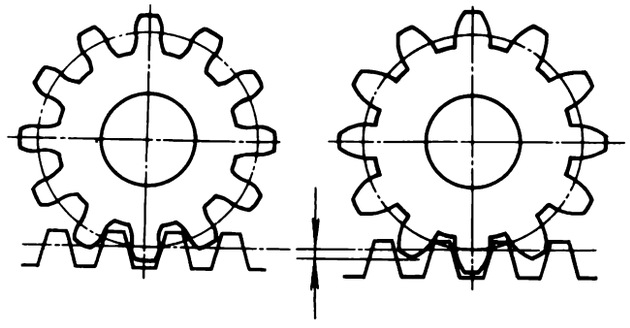


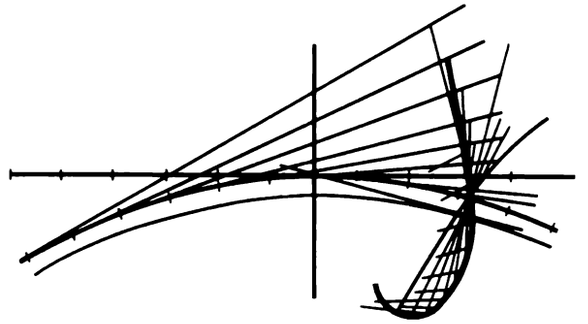
Fig. 489

dedendum is reduced (see Fig. 491*b*). The opposite is true of the gear (the larger one of a pair of mating gears) where the addendum is reduced and the dedendum is increased. This effect is obtained because in cutting the pinion the centre-to-centre distance between the blank and cutting tool is increased, and in cutting the gear it is decreased by the amount of correction. Since the heights are changed, it is called *height correction.*

The amount of radial displacement a of the cutting tool can be readily calculated. If the



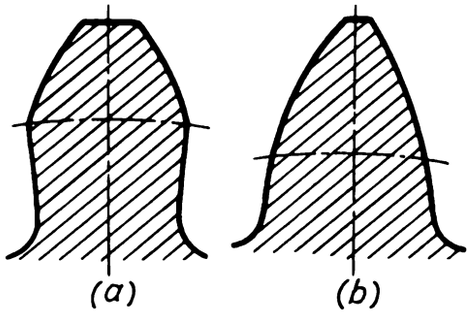
(*a*)



Undercutting an involute tooth profile by the rack profile

(*b*)

Fig. 490



(*a*) (*b*)

Fig. 491

Table 21

Principal Geometric Relationships in Uncorrected Spur Gearing

(Based on the Module m and Number of Teeth z)

Parameter	Design formula
Addendum, h_a	$h_a = m$
Dedendum, h_f	$h_f = 1.25\,m$
Whole depth of teeth, h	$h = h_a + h_f = 2.25\,m$
Pitch diameter, d	$d = mz$
Outside (addendum circle) diameter, d_a	$d_a = d + 2h_a = m(z+2)$
Root (dedencum circle) diameter, d_f	$d_f = d - 2h_f = m(z-2.5)$
Circular pitch, $\widehat{p}_t$	$\widehat{p}_t = \pi m$
Circular thickness of the teeth, $\widehat{s}_t$	$\widehat{s}_t = 0.5\widehat{p}_t = 0.5\pi m$
Circular width of the tooth spaces, $\widehat{e}_f$	$\widehat{e}_f = 0.5\widehat{p}_t = 0.5\pi m$
Fillet radius at the root of the teeth, R_f	$R_f = 0.25m$

number of teeth of the pinion $z_1 < 30$ and the total number of teeth $z_1 + z_2 > 60$, the pertinent ISO standard recommends that the tool displacement factor x, called the *basic rack displacement factor*, be determined by the formula: $x = 0.03 \times (30 - z_1)$. Thus, for example, at $z_1 = 10$ and $z_2 = 52$, their sum is $z_1 + z_2 = 62 > 60$. Then, $x = 0.03(30 - 10) = 0.6$. If the module $m = 5$ mm, the tool is to be displaced away from the centre of the pinion blank in cutting the pinion and toward the centre of the gear blank in cutting the gear by the amount

$$a = xm = 0.6 \times 5 = 3 \text{ mm}$$

Thanks to correction, the pinion can be designed with a smaller number of teeth, thus providing a more compact gearing drive.

Training drawings usually deal with uncorrected involute gearing, whose dimensions (Fig. 487) have a definite relationship with the module m and number of teeth z (Table 21).

Figure 492 illustrates a simple method of tooth profiling developed by engineer Novikov. In this case the profile is not an involute but an arc of a circle.

Novikov's method is meant for gears with helical teeth having a circle-arc profile with a constant curvature along the whole tooth depth. When in mesh, the convex teeth of the pinion contact the concave teeth of the gear over a

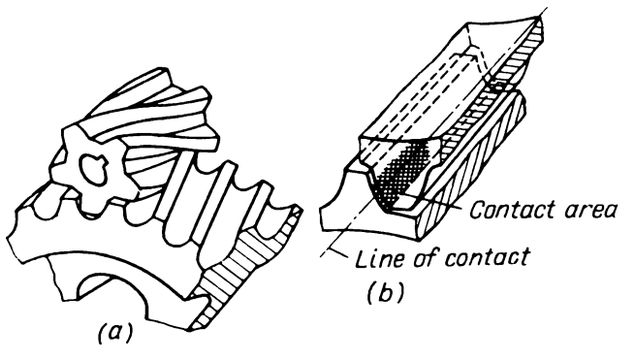


Fig. 492

much larger area than in involute gearing — an important fact which makes it possible to transmit greater loads. One more advantage: the lubricant is retained better between the teeth, thus increasing their wear resistance.

4. TYPES OF GEARS

Today, toothed gears of a great many different designs are used in mechanical engineering. They differ in the manufacturing process used to make them, in material, and in various design features.

Toothed gears are made by forging, rolling, casting and welding. Gears are made of steel, cast iron, bronze and various plastics (polymers). Also used to some extent are reinforced gears, made of a plastic with a metal alloy reinforcement.

The design shape and size of a gear depend upon the load carried by its teeth, requirements of the manufacturing process, operating requirements, etc.

The most common type of gear is the spur gear, i.e., a toothed gear with straight teeth parallel to the gear axis (Fig. 493*a*).

A spur gear of a small diameter may have the shape of a solid cylinder with a hole for mounting on a shaft (Fig. 493*a*).

To lighten a gear of a somewhat larger diameter, only the rim and hub with the hole for the shaft are of heavy design. The rest of the gear is a comparatively thin web (disk) with or without holes. This web may have stiffening ribs (Fig. 493*b*).

If the diameter of the gear is sufficiently large, the web may be replaced by several spokes connecting the rim to the hub. The spokes may be of various shapes. Their cross sections may be

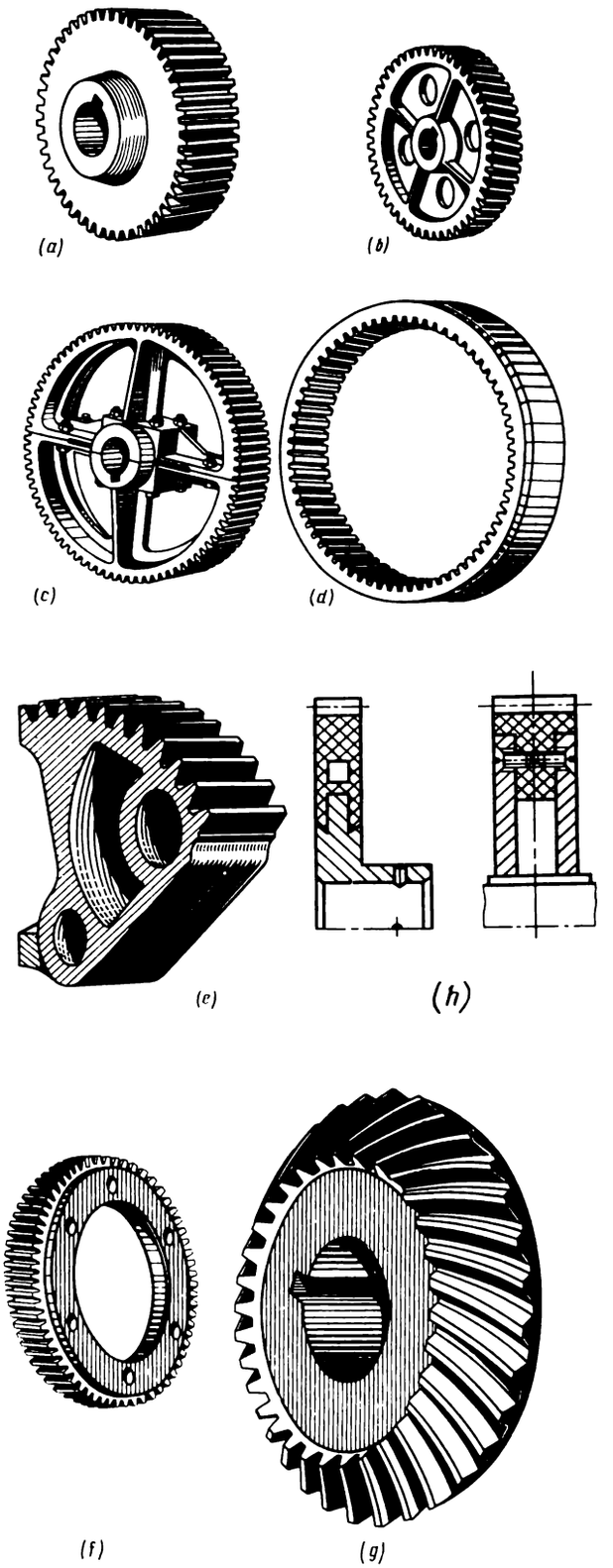


Fig. 493

round, oval, rectangular, I-shaped, cross-shaped, etc.

To ensure convenience in assembly and simplify manufacture, gears of large diameter are sometimes of split design, the two halves being held together by bolts (Fig. 493*c*).

If the design of the machine requires internal gearing, the larger gear of the pair is manufactured with internal teeth (Fig. 493*d*). A shaft can be turned through an angle less than a whole revolution by employing a segment gear (Fig. 493*e*).

The teeth of gears may be straight and parallel to the gear axis, as on spur gears (Fig. 493*a* and *c*), helical (Fig. 493*f*), or curved, as on a curved-tooth (spiral) bevel gear (Fig. 493*g*). Terminology, elements, and definitions concerning gears and gearing are covered by the pertinent standards.

Plastics (polymer) materials, such as textolite, densified laminated wood and, especially, polyamides (capron and caprolon) are highly efficient materials for manufacturing the toothed rims of pinions and gears (Fig. 493*h*). Their advantageous features are: noiseless operation, high wear resistance and durability, low mass (weight), a size not exceeding that of metal gears (with the same transmitted power), flexibility in transmitting force, low cost and low labour input in manufacture.

Capron, for instance, is made of a mixture of scraps and waste of capron fabrics, knitted wear and cotton yarn. Textolite is used to make noiseless pinions and gears of various size, from miniature gears for the mechanisms of electric meters and up to gears one metre or more in diameter for the heavy engineering industries.

The teeth of such gears elastically absorb shocks and impacts. This enables them to retain their profile and proper tooth engagement, and reduces wear. The teeth of the gear rims of densified laminated wood are flexible and noiseless, they operate without lubrication, and are very cheap.

5. DRAWING SPUR GEARS

Ordinarily determined in the design calculations of gears are: module m, number of teeth z, and shaft diameter D_{sh}. These parameters are sufficient to find all the other dimensions of the toothed rims of gears (Fig. 487 and Table 21). The dimensions of the other elements of gears can be determined by relationships based on practice in gear designing (Table 22).

Table 22

Approximate Relationships of Gear Dimensions (Fig. 487)
(Based on the Module m and Shaft Diameter D_{sh})

Gear element	Relationship
Face width of gear, b	$b=(6 \text{ to } 8)m$
Thickness of rim up to root circle, δ_1	$\delta_1=(2.5 \text{ to } 3)m$
Diameter of gear hub, D_h	$D_h=(1.6 \text{ to } 1.8)D_{sh}$
Thickness of web, δ_2	$\delta_2=(3 \text{ to } 3.6)m$
Web hole circle diameter, D'	$D'=0.5(D_r+D_h)$
Diameter of holes in web, D_{hole}	$D_{hole}=\frac{D_r-D_h}{2.5 \text{ to } 3}$
Length of hub, L_h	$L_h=1.5D_{sh}$
Chamfer, S	$S=0.5m\times45°$

Note: The smaller values of the coefficients refer to steel gears, and the greater ones, to cast-iron gears.

The rules for representing gears and gearing in drawings are covered by standards.

Let us draw a spur gear of the design illustrated in Fig. 494.

The steps in drawing such a gear follow.

Given: module $m=8$ mm, number of teeth $z=30$, shaft diameter $D_{sh}=36$ mm; material — steel.

First we calculate the following (see Table 21):

pitch diameter $d=mz=8\times30=240$ mm;

outside diameter $d_a=m(z+2)=8(30+2)=256$ mm;

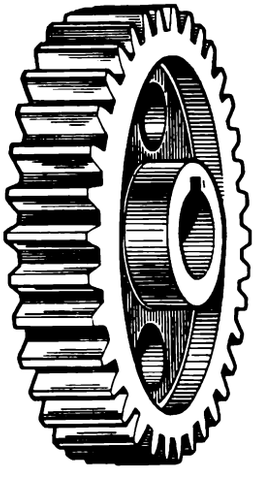


Fig. 494

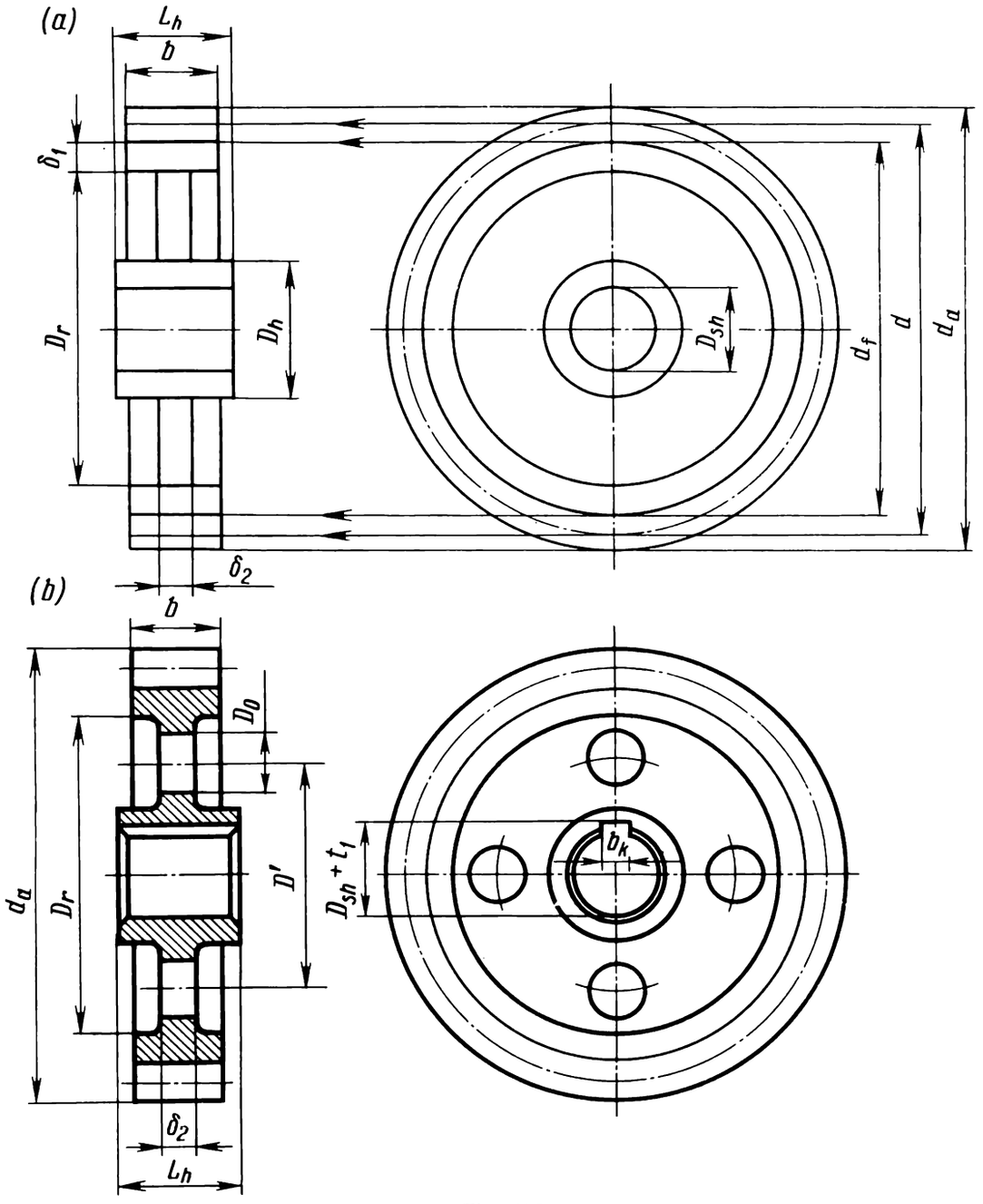


Fig. 495

root diameter $d_f = m(z-2.5) = 8(30-2.5) = 220$ mm.

To construct the left-hand view, three concentric circles are described with diameters $d_a = 256$ mm, $d = 240$ mm, and $d_f = 220$ mm.

Projecting by the lines marked with arrows (Fig. 495*a*), we find the outline of the tooth in the frontal section of the gear.

On the basis of the relationships listed in Table 22, we determine the dimensions of the elements of the gear on its representations.

The face width of the gear, $b = 6m = 6 \times 8 = 48$ mm.

The thickness of the rim up to the root circle, $\delta_1 = 2.5m = 2.5 \times 8 = 20$ mm.

The thickness of the web, $\delta_2 = 3m = 3 \times 8 = 24$ mm.

The diameter of the gear hub, $D_h = 1.6 D_{sh} = 1.6 \times 36 = 58$ mm.

Then the following diameters are determined:

$$D_r = d_f - 2\delta_1 = 220 - (2 \times 20) = 180 \text{ mm}$$

$$D' = 0.5(D_r + D_h) = 0.5(180 + 58) = 119 \text{ mm}$$

and

$$D_{hole} = \frac{D_r - D_h}{2.5} = \frac{180 - 58}{2.5} = 48.8 \approx 48 \text{ mm}$$

The length of the hub is

$$L_h = 1.5 D_{sh} = 1.5 \times 36 = 54 \text{ mm}$$

The dimensions of the keyway are determined according to the pertinent standard (see Chap. 5, Sec. 2):

$$b_k = 10 \text{ mm}, \quad t_1 = 3.6 \text{ mm}, \quad \text{and}$$

$$D_{sh} + t_1 = 36 + 3.6 = 39.6 \text{ mm}$$

After erasing all the construction lines, the drawing of the gear is run over a second time with a pencil for finishing the drawing (Fig. 495*b*): the outside circle should be a thick continuous line, and the pitch circle, a thin chain (dot-and-dash) line.

The elements corresponding to the root circle are drawn in the section view with thick continuous lines. In the left-hand view, the root circle is shown with a thin continuous line (the standard permits the root circle to be omitted in drawings).

6. TRAINING DETAIL DRAWING OF A SPUR GEAR

The rules for making detail (working) drawings of involute spur and helical gears are covered by a CMEA recommendation. According to these rules, a *table of parameters*, consisting of *three parts*, is to be drawn in the *upper right-hand corner of the drawing*. The first part of the table lists the main data required for the gear manufacture; the second, data for the gear inspection with a gear-tooth caliper (see below); and the third part, reference data.

Drawings for school purposes usually have only the first part of this table, whose content and location are shown in Fig. 496, and some data from the second part (chordal thickness of the tooth for inspection with a gear-tooth caliper). The dimensions of the table are shown in Fig. 496. The degree of accuracy with which the teeth are to be cut is determined from the operating conditions of the gear. The pertinent USSR standard establishes 12 grades of accuracy for the manufacture of spur, helical and bevel gears, and wormgears in the order of decreasing accuracy, grade 1 being the most accurate. Six grades of accuracy, the 5th, 6th, 7th, 8th, 9th and 10th, are established for rack and pinion gearing. The standard specifies the following types of gear engagement, which do not depend upon the accuracy grade and are given in the order of increasing backlash: H, E, D, C, B and A. For type H engagement, the minimum backlash equals zero. Usually, type B engagement is recommended.

For school purposes, the grade of accuracy can be selected arbitrarily, for instance, Gr. 7-B, where Gr. 7 stands for the 7th grade, and B for normal backlash. A training detail drawing of a gear is shown in Fig. 496.

Since the left-hand view is not necessary in manufacturing the gear teeth, only the outline of the bore for the shaft and the keyway is shown in this view.

The symbol for the maximum permissible roughness of the side surfaces (profiles) of the teeth is shown on the thin chain (dot-and-dash) line representing the pitch circle. The permissible roughness values for the top land of the teeth and the bottom land of the tooth spaces are shown on the lines representing the outside and root circles.

The following dimensions are to be shown on the drawing of the gear: outside (addendum circle) diameter d_a, face width b, and the size of the chamfer on the outside diameter at the end faces. Other dimensions that should be shown depend upon the design of the gear.

7. MAKING A SKETCH FROM A SPUR GEAR

In making a sketch or drawing from a finished spur gear, it is necessary to determine its parameters. For this purpose:

(1) count the number of teeth z;

(2) measure the outside diameter d_a of the gear.

If the gear has an even number of teeth and its size is not very large, the outside diameter is measured directly with a vernier caliper (Fig. 497*a*). If the diameter is quite large or the number of teeth is odd, the outside diameter is determined as illustrated in Fig. 497*b*. Here the

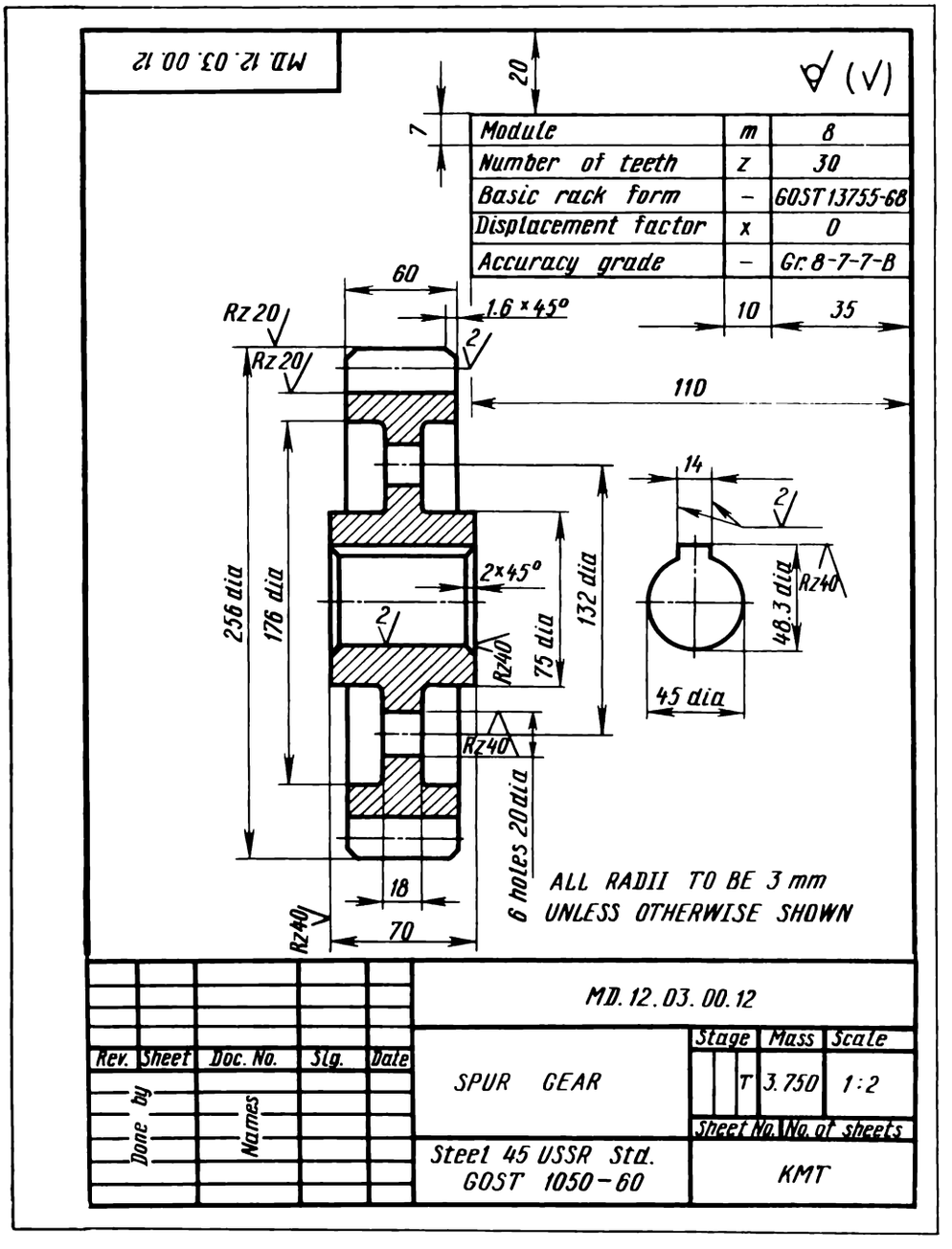


Fig. 496

vernier caliper is used to measure the bore diameter D_{sh} and the dimension n. Then the outside diameter is

$$d_a = D_{sh} + 2n$$

The module of the gear is calculated by the formula

$$m = \frac{d_a}{z+2}$$

and is rounded off to the nearest standard value (see Table 20). Next to be calculated are:

the pitch diameter $d = mz$,

the root diameter $d_f = m(z-2.5)$,

and the final value of the outside diameter is found: $d_a = m(z+2)$.

Errors are frequently made in training practice in measuring the teeth of pinions and gears (chordal thickness, pitch, module, various diam-

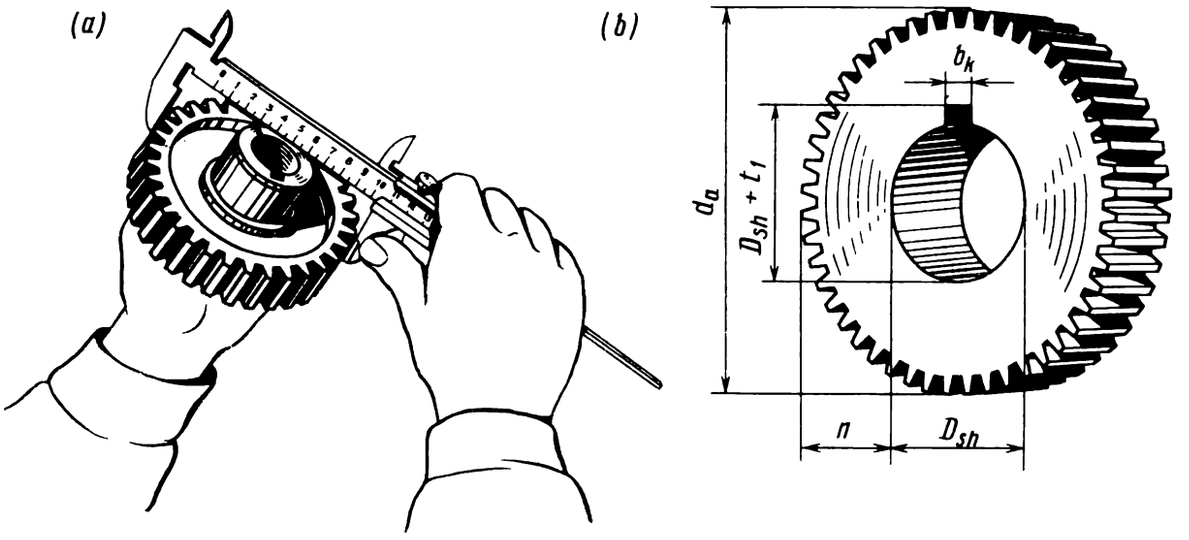


Fig. 497

eters, etc.) because of the inaccuracy of general-purpose measuring tools.

If the tooth thickness is greater than required, the mating gears cannot be installed at the specified centre distance a_w. If the teeth are made thinner in manufacture, excessive backlash occurs when the gears are installed. This leads to excessive noise and intensive wear in the meshing of the teeth.

The shape of the surface of contact between the teeth of the mating gears (tooth contact pattern), obtained when the teeth of one of the gears are coated with a marking compound, is shown in Fig. 498. Shown in Fig. 498*a* is the symmetrical contact pattern obtained when the mating gears mesh normally with guaranteed backlash (see Fig. 498*b*). When the centre distance is increased or decreased, the contact pattern obtained will be as shown in Fig. 498*c* and *d*. These last two illustrations indicate that the side surfaces of the teeth are nonsymmetrically loaded.

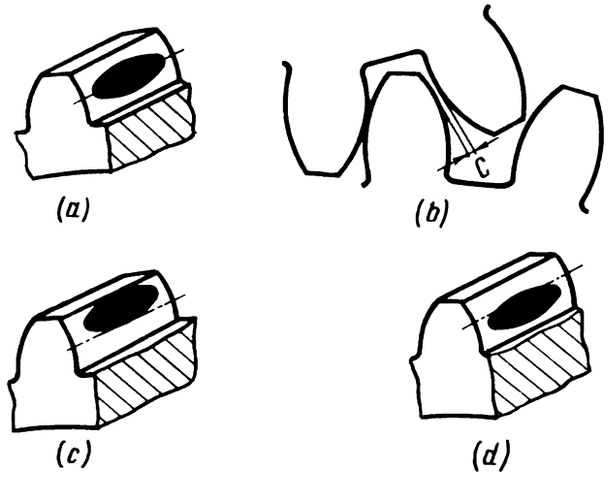


Fig. 498

It is good practice, therefore, after using ordinary measuring tools (for example, a vernier caliper), to check the tooth thickness with a special mechanical or optical *vernier gear-tooth caliper*.

A mechanical vernier gear-tooth caliper (Fig. 499) has two beams at right angles with scales and verniers. One beam with its scale (horizontal B) serves to measure the chordal thickness $\bar{s}$ of the tooth (on a chord of the pitch circle). The second beam with its scale (vertical A) is for setting the caliper to the chordal addendum (distance from the chord to the outside diameter) $\bar{h}_a$ (see Fig. 500).

In checking the tooth thickness with a gear-tooth caliper, after first determining the circular thickness of the teeth by the formula $\hat{s}_t=\frac{\hat{p}_t}{2}=\frac{mz}{2}$, it is necessary to calculate the chordal thickness $\bar{s}$ and the chordal addendum $\bar{h}_a$.

A. The chordal thickness $\bar{s}$ is found from right triangle ABO, where side AB is equal to the product of the hypotenuse AO multiplied by $\sin\beta/2$, i.e.,

$$\frac{\bar{s}}{2}=\frac{d}{2}\sin\frac{\beta}{2} \quad \text{or} \quad \bar{s}=d\sin\frac{\beta}{2}$$

where angle $2\beta=\frac{360}{z}$.

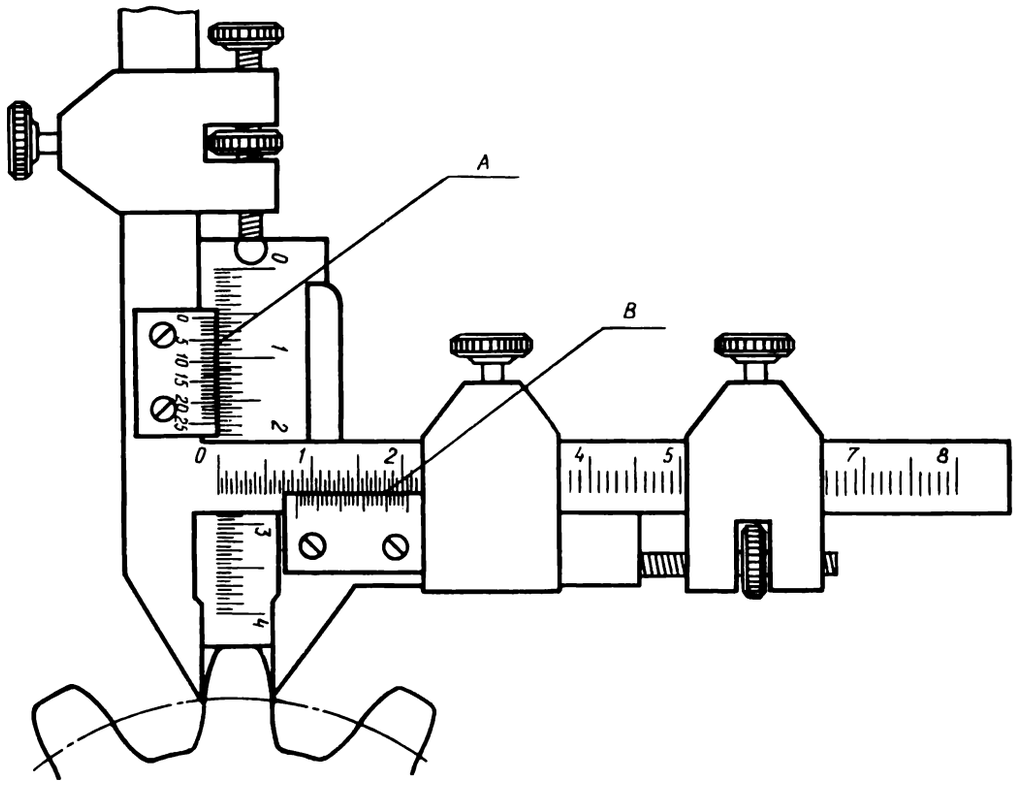


Fig. 499

B. The chordal addendum $\bar{h}_a$ is the difference of the radius of the outside circle $\frac{d_a}{2}$ and the side *BO* of the same right triangle *ABO*.

Thus,

$$\bar{h}_a=\frac{d_a}{2}-\frac{d}{2}\cos\frac{\beta}{2}=0.5\left(d_a-d\cos\frac{\beta}{2}\right)$$

These calculations can be simplified by the use of chordal addendum factors q' and chordal thickness factors s' (Table 23). Accordingly, $\bar{h}_a=q'm$ and $\bar{s}=s'm$. For example, for a gear with $m=2.5$ mm and $z=21$, we find from Table 23 the factors: $q'=1.0293$ and $s'=1.5693$. Then $\bar{h}_a=q'm=1.0293\times2.5=2.57325$ mm and $s=s'm=1.5693\times2.5=3.92325$ mm.

The dimensions of all the other elements of the gear (face width, keyway dimensions, etc.) are determined by measuring the gear being sketched.

The drawing is made by analogy with the example given in Fig. 495. The sketch or detail drawing is made according to the example illustrated in Fig. 496.

Table 23

Number of teeth z of spur gear	q'	s'
$z=10$ teeth	1.0615	1.5643
11	1.0559	1.5654
12	1.0513	1.5663
13	1.0473	1.5669
14	1.0440	1.5675
15	1.0410	1.5679
16	1.0385	1.5682
17	1.0362	1.5685
18	1.0342	1.5688
19	1.0324	1.5690
20	1.0308	1.5691
21	1.0293	1.5693
22	1.0280	1.5694

Note: All the calculation data are valid for standard involute gearing which, as a rule, the student will deal with.

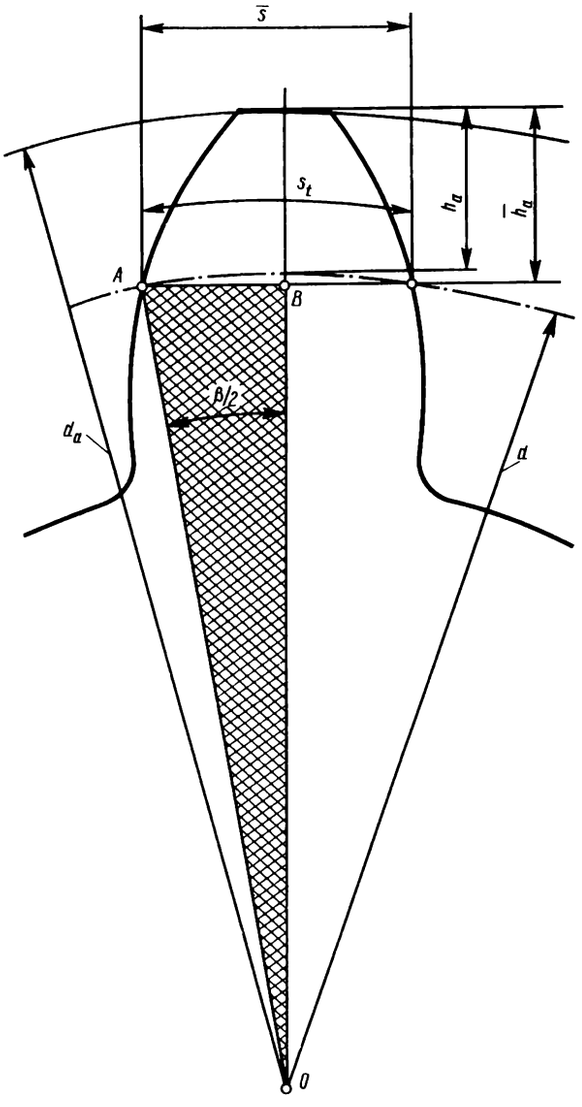


Fig. 500

8. DRAWING SINGLE-STAGE SPUR AND HELICAL GEARING

Spur and helical gears are used to transmit rotation from one shaft to another, the axes of the shafts being parallel (Fig. 501*a*).

The gear which imparts motion to the other (mating) gear of the drive is called the *driving gear*. The gear to which motion is imparted by the driving gear is called the *driven gear*. Of the two gears, the one having the smaller number of teeth is commonly called the *pinion*. The mating gear is simply called the gear. When mating gears have the same number of teeth, the driving gear is commonly called the pinion, and the driven gear, the gear.

In the notation for the elements of gears, subindex 1 refers to the pinion, and subindex 2, to the gear.

Most of the gears dealt with in the drawing course are spur gears, i.e., gears with straight teeth parallel to the gear axis.

The standard that covers the representation of gearing in drives specifies that the lines corresponding to the rolling surfaces be shown on drawings.

In spur and helical gearing, the rolling surfaces are cylinders that correspond to the rolling circles.

The uncorrected gears used in the drives in the drawing course are to be manufactured without displacement of the basic rack form (profile). Therefore, in training drawings of gearing, the rolling circles coincide with the pitch circles (Fig. 501*b*).

Let us, for example, make a drawing of the single-stage drive illustrated in Fig. 501*a*, according to the following data:

(1) type of gears — spur;

(2) module of the gearing, $m=12$ mm (design module);

(3) number of teeth on the pinion, $z_1=16$;

(4) number of teeth on the gear, $z_2=48$;

(5) face width, $b=100$ mm;

(6) diameters of the bores for the shafts: pinion — $D_{sh1}=65$ mm; gear — $D_{sh2}=90$ mm.

First we calculate the parameters of the gears from the formulas listed in Tables 21 and 22.

(1) Pitch diameters:

$d_1=mz_1=12\times 16=192$ mm;
$d_2=mz_2=12\times 48=576$ mm.

(2) Outside and root diameters:

$d_{a1}=d_1+2m=192+2\times 12=216$ mm;
$d_{a2}=d_2+2m=576+2\times 12=600$ mm;
$d_{f1}=d_1-2.5m=192-2.5\times 12=162$ mm;
$d_{f2}=d_2-2.5m=576-2.5\times 12=546$ mm.

(3) Hub diameters:

$D_{h1}=1.6D_{sh1}=1.6\times 65=104$ mm;
$D_{h2}=1.6D_{sh2}=1.6\times 90=144$ mm.

(4) Hub lengths:

$L_{h1}=1.5D_{sh1}=1.5\times 65\approx 98$ mm;
$L_{h2}=1.5D_{sh2}=1.5\times 90=135$ mm.

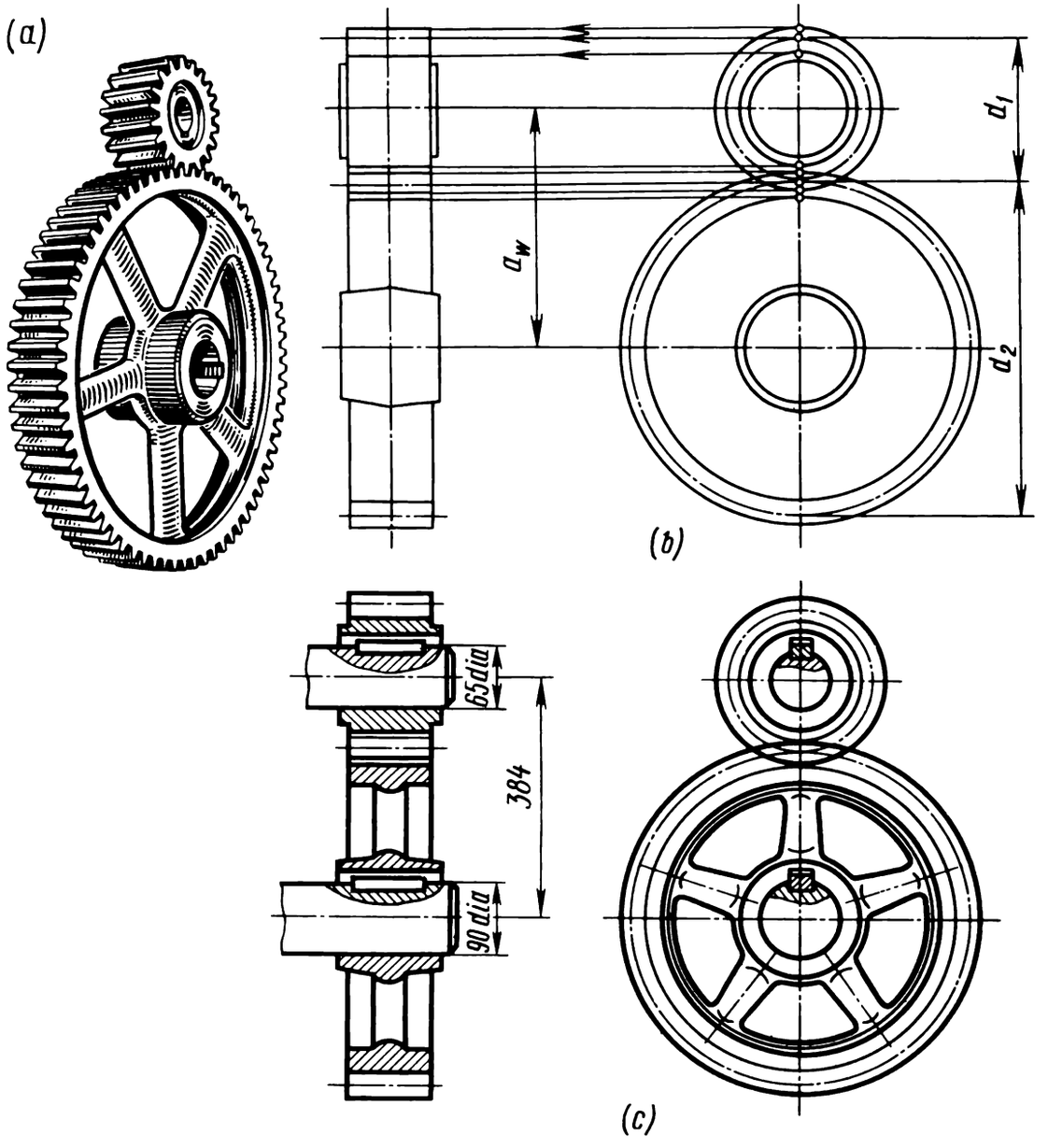


Fig. 501

After calculating the pitch diameters of the pinion and gear, d_1 and d_2, we can find the centre distance of the gearing. This is the distance between the axes of the mating gears.

In our case, the centre distance is

$$a_w = 0.5(d_1 + d_2) = 0.5(192 + 576) = 384 \text{ mm}$$

The drawing of the gearing is constructed with thin lines and begins with laying off the centre distance a_w, drawing the axes in the left-hand view, and then describing the pitch circles, d_1 and d_2 (these circles should be tangent at a point lying on the axis connecting the centres of the two gears), outside circles, d_{a1} and d_{a2}, and the root circles, d_{f1} and d_{f2} (Fig. 501*b*). Then the circles depicting the bores for the shafts, D_{sh1} and D_{sh2}, are described, as well as the outside circles of the hubs, D_{h1} and D_{h2}.

To construct the frontal section, the intersections of the circles with the vertical axis are projected in the direction of the arrows. When the construction is finished, the drawing is com-

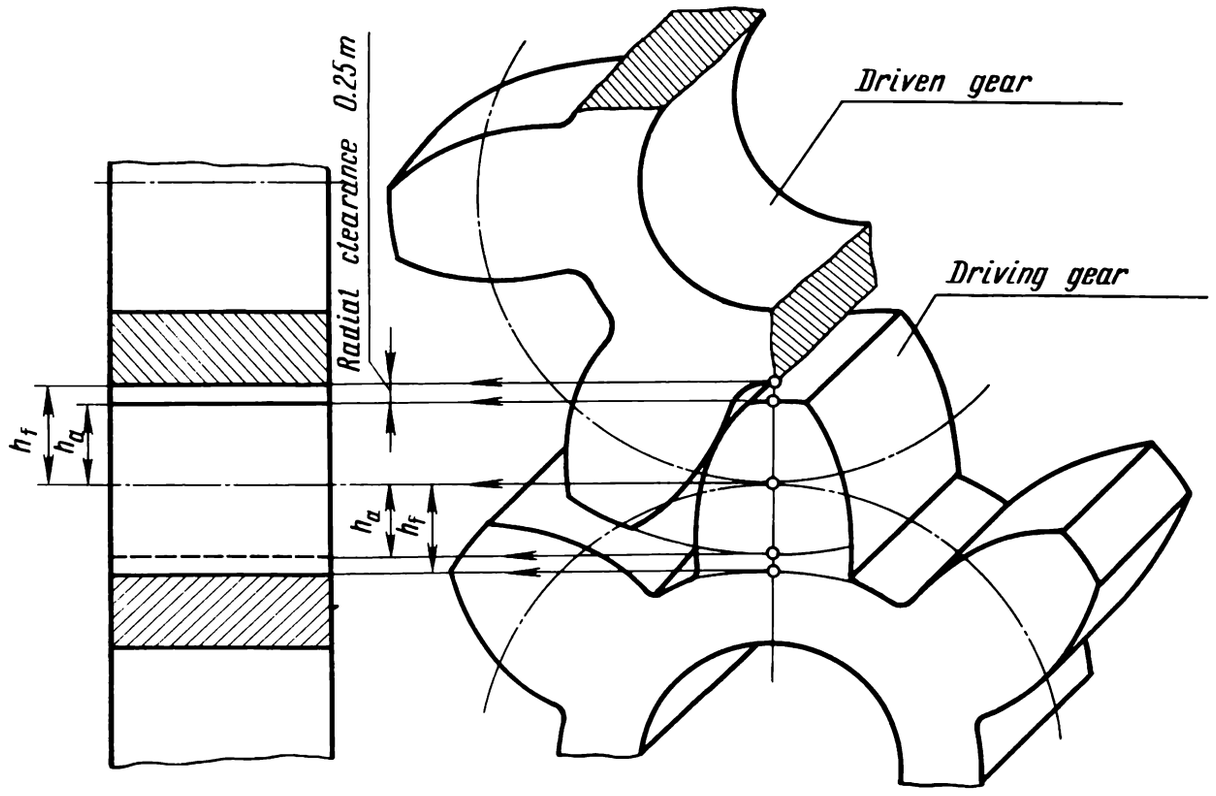


Fig. 502

pleted by drawing in the various details (Fig. 501*c*). The hubs of the gears are drawn in on both views. The dimensions of the keyways are taken from the standard (see Table 16) to suit the diameters of the shafts. Broken-out sections of the shafts are drawn at the key joints. Then the spokes are drawn. Their number, shape and dimensions are assumed to be given. All unnecessary lines are erased. The contour lines are run over a second time with a pencil. Section views are cross-hatched. In the frontal section, the tooth of the driving gear is shown in front of that of the driven gear. This is clearly shown by the example illustrated in Fig. 502. Owing to the difference between the addendum and dedendum, radial clearances are obtained.

On the left-hand view, the outside (addendum) circles of both gears in the zone of tooth engagement are described with thick continuous lines.

9. STRAIGHT BEVEL GEARING

Bevel gearing is employed to transmit rotation between intersecting shafts (Fig. 482*b*).

If the angle between the intersecting axes of the shafts (shaft angle) equals 90°, the bevel gearing is said to be *miter gearing;* if the shaft angle is not equal to 90°, it is said to be *angular gearing.*

The drawing course deals mainly with miter gearings in which straight bevel gears are used. A straight bevel gear has its teeth arranged along the elements of the pitch cone.

10. DRAWING STRAIGHT BEVEL GEARS

The shape and dimensions of a bevel gear tooth (Fig. 503*a*) are determined by the following conical surfaces (Fig. 503*b*): the *pitch cone*, the *outside*, or *face, cone*, the *root cone*, and the *back cone* whose elements are perpendicular to those of the pitch cone.

In making drawings, it is assumed that the pitch cone, the outside cone and the root cone have a common apex.

The profile of the teeth at the large end is called the *back cone profile*, and the gear dimensions are specified here. The pitch circle is the intersection of the pitch and back cones. In other words, the pitch circle passes through the

back cone profile. The pitch circle is specified by the pitch diameter, and it corresponds to the large end module m_e on the back cone. The numerical value of the module is determined as for spur gears from a standard series (see Table 20).

The addendum and dedendum of a bevel gear are measured along the elements of the back cone.

The relationships given below enable one to determine dimensions of the toothed rim of a bevel gear (Fig. 503*b*) for miter gearing specified by the following data: large end module m_e, number of teeth of the pinion, z_1, and the number of teeth of the gear, z_2.

Then:

the pitch diameter of the pinion, $d_1 = m_e z_1$;

the pitch diameter of the gear (line-segment $\overline{DD_1}$), $d_2 = m_e z_2$;

the addendum (line-segment $\overline{AD}$ or $\overline{A_1D_1}$), $h_a = m_e$;

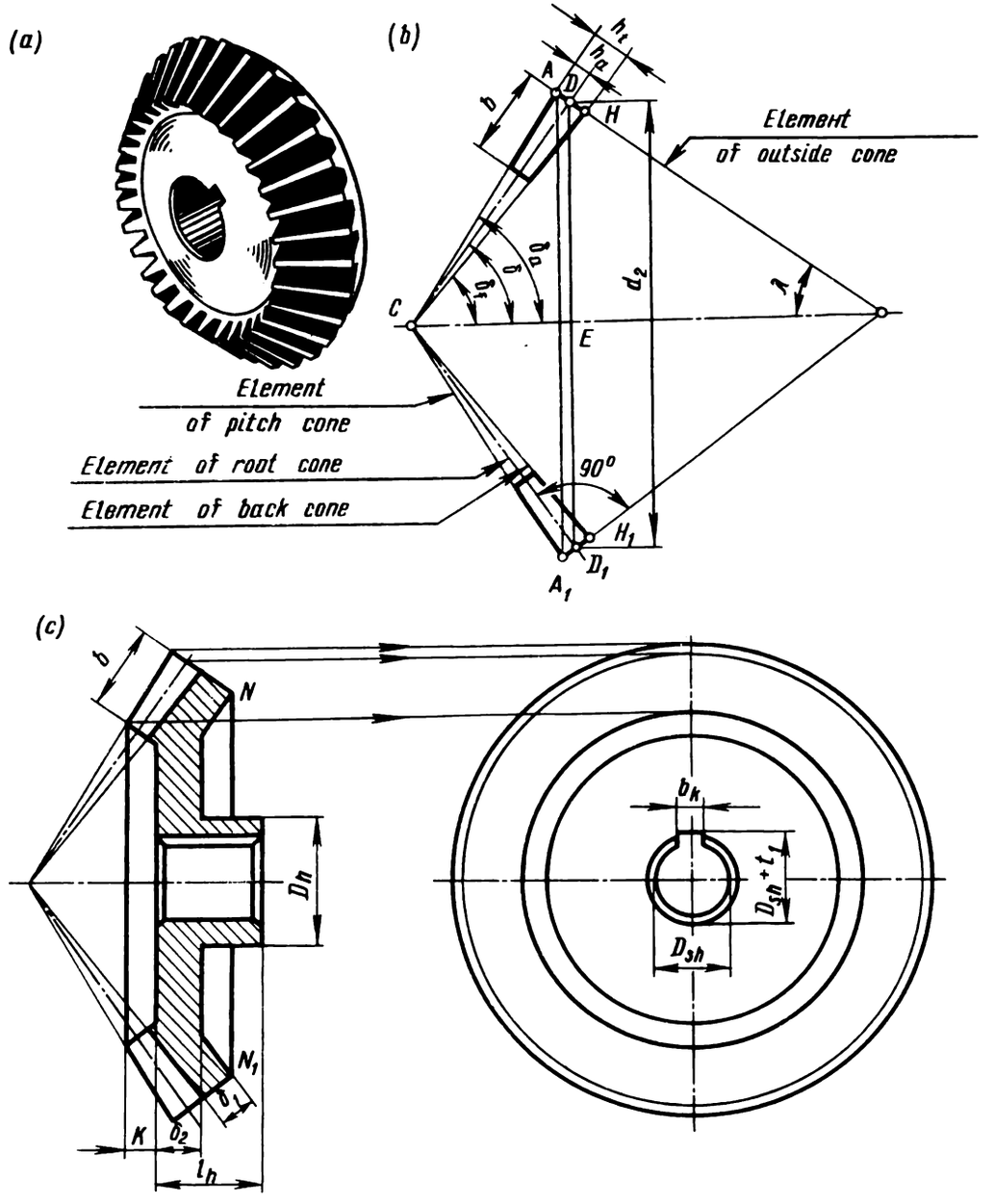


Fig. 503

the dedendum (line-segment $\overline{HD}$ or $\overline{H_1D_1}$), $h_f = 1.2m_e$;

the whole depth of teeth (line-segment $\overline{AH}$ or $\overline{A_1H_1}$), $h = h_a + h_f = 2.2m_e$.

The cone distance (line-segment $\overline{CD}$),

$$L = \sqrt{\overline{EC}^2 + \overline{ED}^2} = \sqrt{(0.5m_e z_1)^2 + (0.5m_e z_2)^2}$$

or, after transformation,

$$L = 0.5m_e\sqrt{z_1^2 + z_2^2}$$

The pitch angle, δ_2, of the gear is determined from its tangent which, in right triangle DEC, equals

$$\tan \delta_2 = \frac{\overline{ED}}{\overline{EC}}$$

Since $\overline{ED} = 0.5\overline{DD_1} = 0.5d_2 = 0.5m_e z_2$ and, in the same way, $\overline{EC} = 0.5d_1 + 0.5m_e z_1$,

$$\tan \delta_2 = \frac{z_2}{z_1}$$

The face angle of the gear $\delta_{a2} = \delta_2 + \gamma$, where angle γ (angle DCA) is determined from its tangent which, in right triangle ADC, equals

$$\tan \gamma = \frac{\overline{AD}}{\overline{DC}} = \frac{m_e}{0.5m_e\sqrt{z_1^2 + z_2^2}}$$

or, after transformation,

$$\tan \gamma = \frac{2}{\sqrt{z_1^2 + z_2^2}}$$

The root angle of the gear is $\delta_{f2} = \delta_2 - \varepsilon$, where angle ε (angle DCH) is determined from its tangent which, in right triangle HDC, equals

$$\tan \varepsilon = \frac{\overline{HD}}{\overline{DC}} = \frac{1.2m_e}{0.5m_e\sqrt{z_1^2 + z_2^2}} \text{ or } \tan \varepsilon = \frac{2.4}{\sqrt{z_1^2 + z_2^2}}$$

The back angle λ_2 of the gear is determined by the formula $\lambda_2 = 90° - \delta_2$. The pitch angle of the pinion, $\delta_1 = \lambda_2$.

Employing these relationships, we shall discuss an example of the construction of a miter gearing specified by the following data:

(1) module, $m_e = 6$ mm;
(2) the number of teeth on the pinion, $z_1 = 20$;
(3) the number of teeth on the gear, $z_2 = 30$;
(4) the diameter of the gear shaft, $D_{sh} = 30$ mm;
(5) the gear is made of steel and is keyed to its shaft with a straight key.

First we determine the dimensions of the toothed rims, as they will be required in constructing the representations:

the pitch diameter of the pinion is

$$d_1 = m_e z_1 = 6 \times 20 = 120 \text{ mm}$$

the pitch diameter of the gear is

$$d_2 = m_e z_2 = 6 \times 30 = 180 \text{ mm}$$

the addendum is

$$h_a = m_e = 6 \text{ mm}$$

the dedendum is

$$h_f = 1.2m_e = 1.2 \times 6 = 7.2 \text{ mm}$$

We begin the construction (Fig. 503*b*) with the frontal section. We lay off line-segment $\overline{CE} = 0.5d_1 = 0.5 \times 120 = 60$ mm along the axis of the gear and, perpendicular to this axis, line-segments $\overline{ED} = 0.5d_2 = 0.5 \times 180 = 90$ mm and $\overline{ED_1} = 90$ mm.

Connecting points D and D_1 with the apex C of the pitch cone, we obtain the contour of this cone.

At points D and D_1 we erect perpendiculars to the elements of the pitch cone (thus obtaining the elements of the back cone), on which we lay off:

the addendum, $h_a = \overline{DA} = 6$ mm;

the dedendum, $h_f = \overline{DH} = 7.2$ mm.

Connecting points A, H, A_1 and H_1 with apex C, we obtain the face and root cones.

Before completing the drawing, we must calculate the design elements of the gear, using the relationships listed in Table 23.

From point D along the generator of the pitch cone (Fig. 503*b*), toward apex C, we lay off the face width $b = 6m_e = 6 \times 6 = 36$ mm.

The other elements of the gear are calculated as follows.

The thickness of the rim up to the root cone is $\delta_1 = 2.5m_e = 2.5 \times 6 = 15$ mm. We lay off two line-segments of this length along the elements of the back cone, and connect points N and N_1 thus obtained with a straight line (Fig. 503*c*).

The thickness of the web is $\delta_2 = 3m_e = 3 \times 6 = 18$ mm, and it is to be located at a distance $k \approx 2m_e = 2 \times 6 = 12$ mm from the contour of the left edge of the gear. The hub is drawn after calculating its length and diameter: $L_h = 1.5D_{sh} = 1.5 \times 30 = 45$ mm and $D_h = 1.6D_{sh} = 1.6 \times 30 = 48$ mm.

The bore in the hub (as given) is $D_{sh}=30$ mm. Using Table 16, we find the dimensions for a standard keyway: $b_k=8$ mm and $t_1=3.1$ mm. Then we calculate the dimension $D_{sh}+t_1=30+3.1=33.1$ mm.

According to a convention covered by a standard, on the left-hand view of the gear we show the addendum circles at the large (outside circle) and small ends of the teeth with thick continuous lines, and the pitch circle with a thin chain (dot-and-dash) line. The other circles referring to the toothed rim are *not shown.*

When the construction is finished, the frontal section and the left-hand view are finally run over a second time and the section is cross-hatched as required (Fig. 503*c*).

11. TRAINING DETAIL DRAWING OF A STRAIGHT BEVEL GEAR

The detail (working) drawings of bevel gears are to be made according to a drawing standard.

Shown in Fig. 504 is a detail drawing of the bevel gear whose construction has been discussed above and illustrated in Fig. 503. The table of parameters is simplified, as is the usual practice for training drawings.

Since the gear has no spokes or holes in the web, only the frontal section is shown in the drawing. In place of the left-hand view, only the outline of the hole in the hub is shown with the dimensions of the keyway.

Dimensions to be shown in the drawing are:

(a) the outside diameter, i.e., the diameter of the base of the face cone (187.5 mm);

(b) the distances from the base of the face cone (a point called the crown) and from the apex of the pitch cone to the back end face of the hub (35 mm and 90 mm);

(c) the length of an element of the pitch cone, called the cone distance (108.2 mm);

(d) the face width of the teeth along an element of the pitch cone (36 mm);

(e) pitch and back angles, as well as the face and root angles (56° 19′, 33° 41′, 59° 29′, and 52° 31′);

(f) other dimensions of the bevel gear (diameters of the hub and bore, the shaft keyway dimensions, chamfers, etc.);

(g) grade of gear accuracy according to the standard (Gr. 7-B).

Some of this information is specified on the drawing, the rest being listed in a special table of parameters given on the drawing. A part of the table stipulated by the drawing standard is shown in Fig. 504. It lists the data required for the manufacture of the gear.

Some of the information that is to be specified in the drawing can be calculated by the formulas obtained in the discussion of the example shown in Fig. 503. Thus, for instance, $\tan \delta_2=\frac{z_2}{z_1}=\frac{30}{20}=1.5$ enables us to find the pitch angle, which is $\delta_2=56°\ 19'$.

The back cone angle, or simply the back angle, is

$$\lambda_2=90°-\delta_2=90°-56°\ 19'=33°\ 41'$$

The cone distance is

$$L=0.5m_e\sqrt{z_1^2+z_2^2}=0.5\times 6\sqrt{20^2+30^2}=108.2 \text{ mm}$$

To find angle γ we calculate its tangent:

$$\tan \gamma=\frac{2}{\sqrt{z_1^2+z_2^2}}=\frac{2}{\sqrt{20^2+30^2}}=0.055$$

This corresponds to angle $\gamma=3°\ 10'$. Then the face angle is $\delta_{a2}=\delta_2+\gamma=56°\ 19'+3°\ 10'=59°\ 29'$. From the tangent

$$\tan \varepsilon=\frac{2.4}{\sqrt{z_1^2+z_2^2}}=\frac{2.4}{\sqrt{20^2+30^2}}=0.066$$

we find angle $\varepsilon=3°\ 48'$, and the root angle then is

$$\delta_{f2}=\delta_2-\varepsilon=56°\ 19'-3°\ 48'=52°\ 31'$$

The remaining parameters of the gear are determined in accordance with the geometric shape of the gear, taking into account the values calculated above.

12. MAKING A SKETCH FROM A STRAIGHT BEVEL GEAR

In making a sketch or drawing from a finished straight bevel gear, it is necessary to determine its module m_e.

We begin with measuring the back angle λ with a protractor (Fig. 505). Then we find the pitch angle $\delta=90°-\lambda$.

After measuring the outside diameter d_a and counting the number z of teeth, we can determine the module m_e. For this purpose, we consider right triangle AFD (Fig. 506). The hypotenuse AD is equal to the tooth addendum $h_a=m_e$. Side AF is equal to the difference in the

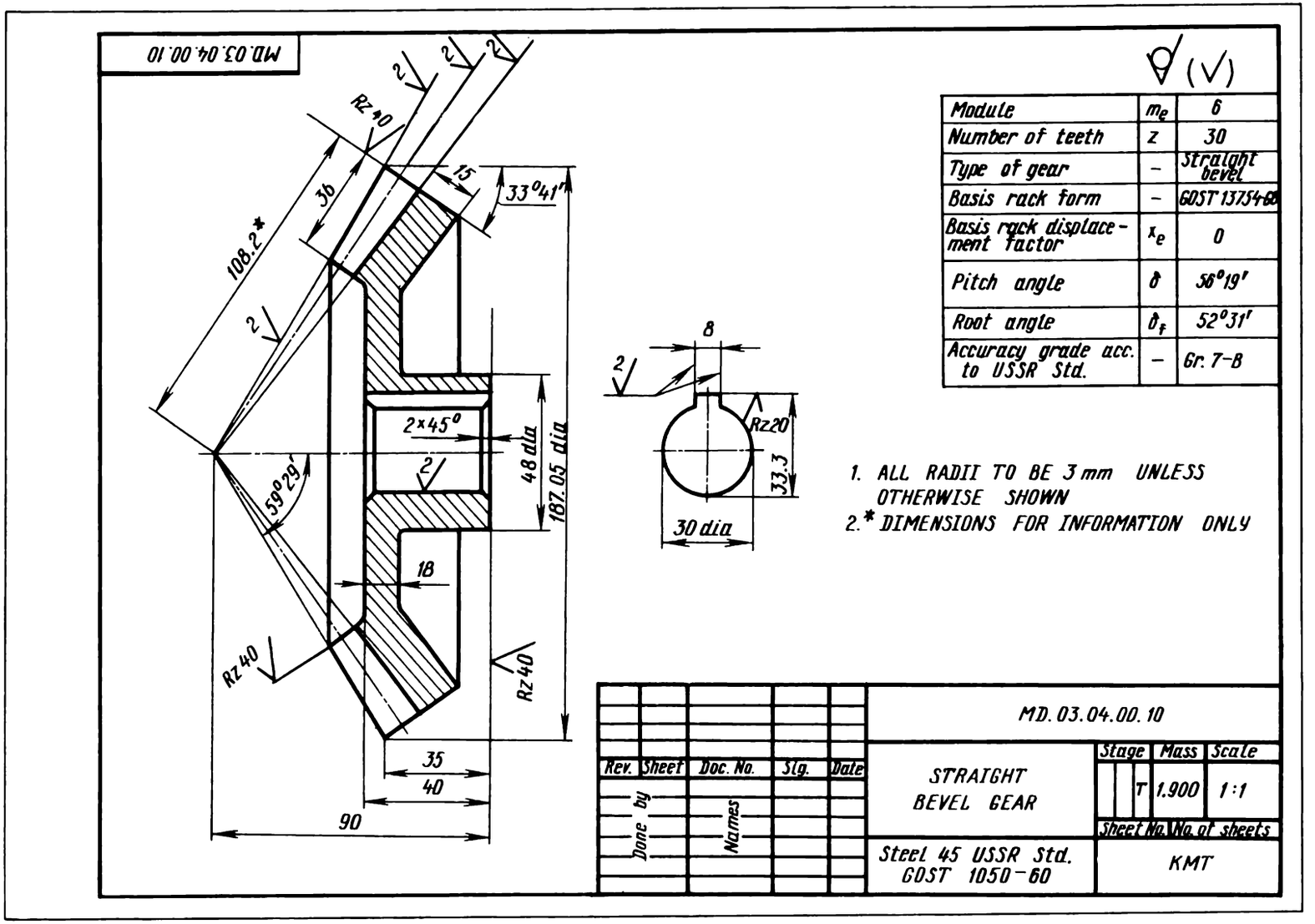

MD.03.04.00.10
Rz40
2
15
33°41'
36
108.2*
2×45°
48 dia
187.05 dia
59°29'
18
Rz40
Rz40
35
40
90
8
Rz20
33.3
30 dia
Module mₑ 6
Number of teeth z 30
Type of gear – Straight bevel
Basis rack form – GOST 13754-68
Basis rack displacement factor xₑ 0
Pitch angle δ 56°19'
Root angle δf 52°31'
Accuracy grade acc. to USSR Std. – 6r. 7-B
1. ALL RADII TO BE 3 mm UNLESS OTHERWISE SHOWN
2.* DIMENSIONS FOR INFORMATION ONLY
MD.03.04.00.10
Rev. Sheet Doc. No. Sig. Date
Done by Names
STRAIGHT BEVEL GEAR
Stage Mass Scale
T 1.900 1:1
Sheet No. No. of sheets
Steel 45 USSR Std. GOST 1050-60
KMT

Fig. 504

radii of the outside and pitch circles: $\overline{AF}=\frac{d_a-d}{2}$.

Angle DAF is equal to angle δ (corresponding sides of the angles are perpendicular to each other). Therefore

$$\overline{AF}=\overline{AD}\cos\delta=m_e\cos\delta=\frac{d_a-d}{2}$$

But, since $d=m_e z$, we can write

$$m_e\cos\delta=\frac{d_a-m_e z}{2}$$

from which

$$m_e=\frac{d_a}{z+2\cos\delta}$$

Rounding off the value of m_e to the nearest standard value, we determine $d=m_e z$. Then we measure the face width b and the other elements of the bevel gear. Finally, we draw the gear similar to the one shown in Fig. 503.

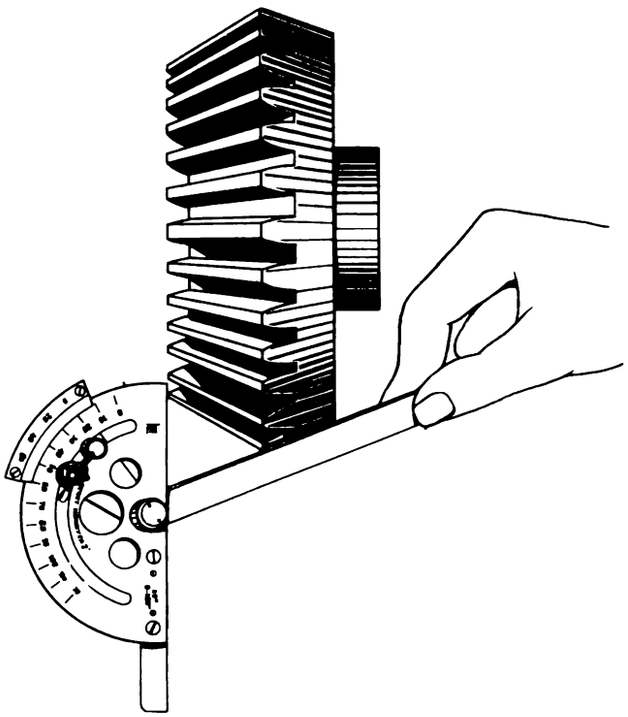


Fig. 505

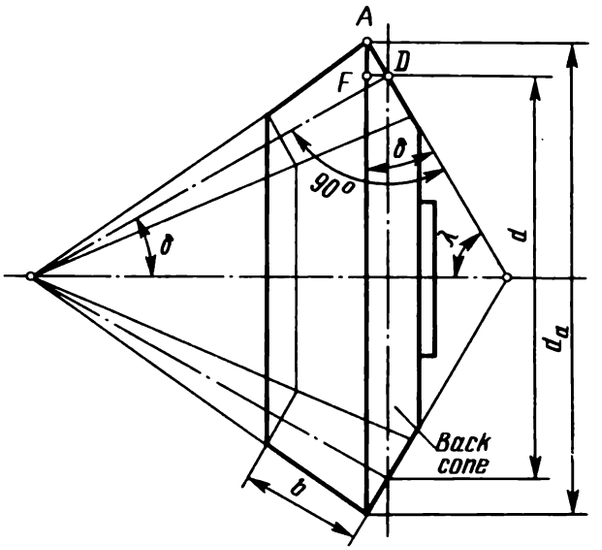


Fig. 506

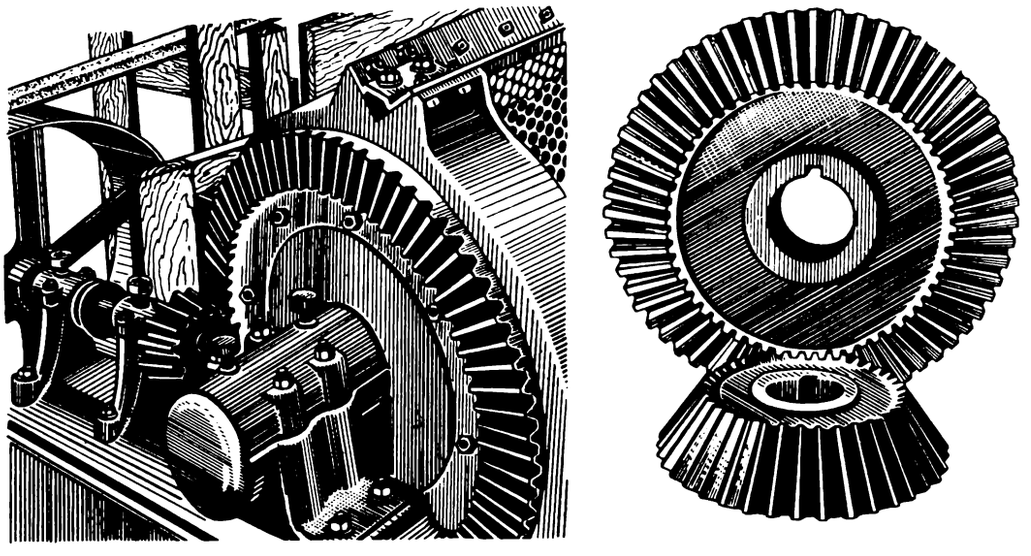


Fig. 507

13. DRAWING MITER GEARING

The bevel gearing (Fig. 507) is represented according to rules stipulated in the pertinent standards.

Before drawing the gearing, the following data must be available for determining the parameters of the gears (these may be measured from finished gears or obtained by calculations):

(1) module, m_e mm;
(2) numbers of teeth, z_1 and z_2;
(3) pitch angles, δ_1 and δ_2;
(4) shaft diameters, D_{sh1} and D_{sh2}.

When these are available, the following can be determined:

(1) addendum and dedendum, h_a and h_f;
(2) pitch diameters, d_1 and d_2;
(3) face widths, b;
(4) diameters and lengths of the hubs, D_{h1}, D_{h2}, L_{h1} and L_{h2};
(5) keyway dimensions;
(6) other elements of the gears concerning their design and operating conditions (thickness of the rim up to the root cone, web thickness, etc.).

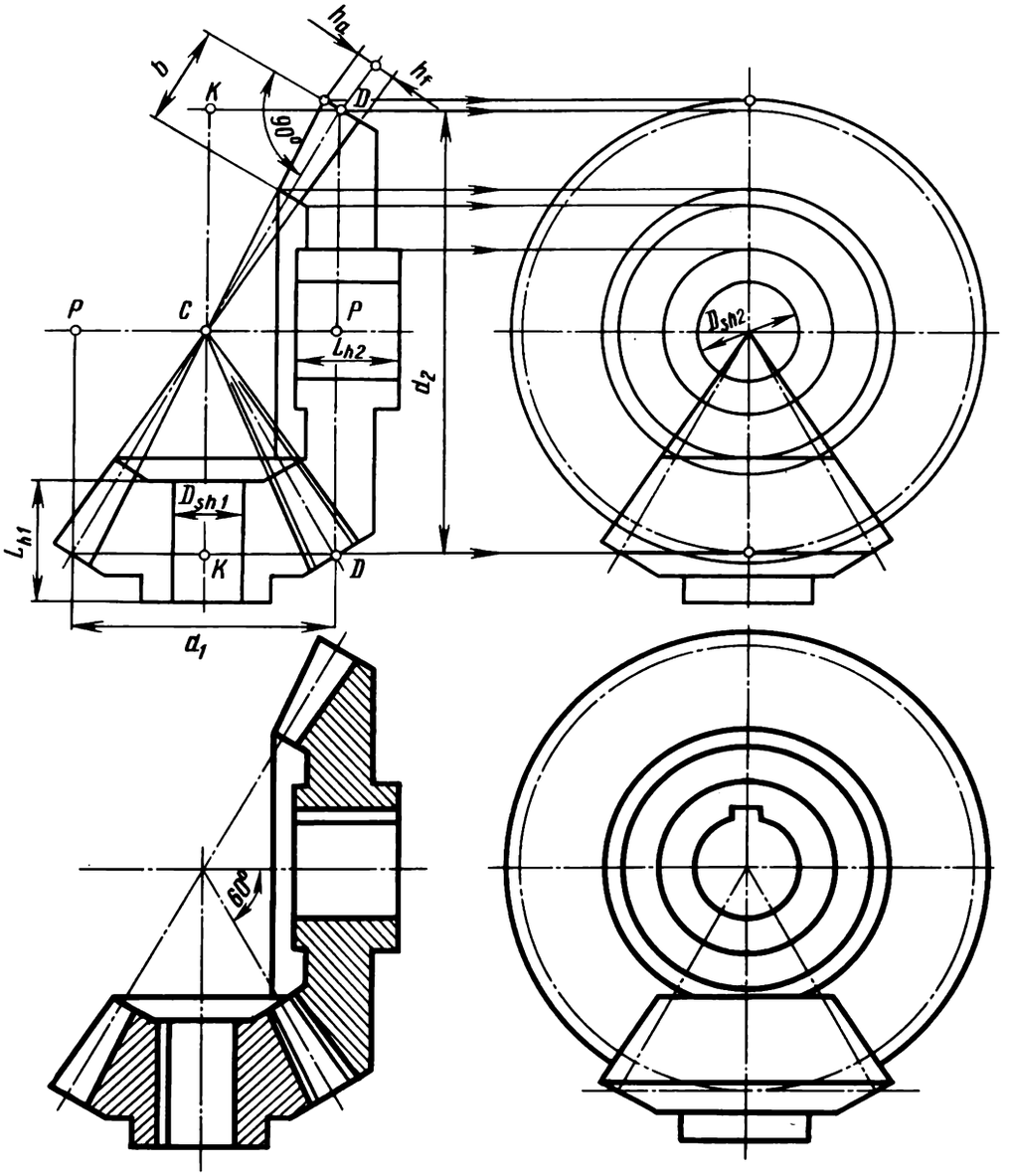


Fig. 508

A drawing of bevel gearing is usually made in the following order:

1. On the main view, which in the given example is to be a frontal section, perpendicular lines are drawn for the axis of the pinion (vertically) and the axis of the gear (horizontally) (Fig. 508).

2. From the point of intersection, of these axes, C we lay off line-segments $\overline{CK}$, equal to $\frac{d_2}{2}$, vertically above and below point C, and line-segments $\overline{CP}$, equal to $\frac{d_1}{2}$, horizontally to the right and left of point C.

3. Through points K we draw horizontal lines, and through points P, vertical lines up to their intersection at points D.

Points D are then connected with point C by lines which represent the elements of the pitch cones of the pinion and gear.

4. At points D we erect perpendiculars to the elements of the pitch cones to obtain the elements of the back cones on which we lay off the addendum $h_a = m_e$ and dedendum $h_f = 1.2m_e$.

5. From the tops and roots of the teeth thus laid off on the back cones, we draw lines to point C, obtaining the elements of the face and root cones.

6. Along the elements of the pitch cones, the face width of the teeth is laid off from points D in the direction of point C. This enables the end faces of the teeth to be drawn perpendicular to the elements of the pitch cones.

7. The outlines of the design elements of the gears are drawn (hubs, bores in them, etc.).

8. The left-hand view is constructed by projecting with horizontal lines. As to the toothed rim of the gear in this view, the pitch circle is shown with a thin chain (dot-and-dash) line, and the outside (addendum) circles at the large and small ends of the teeth, with thick continuous lines.

9. To finish the drawing, all unnecessary lines are erased, the frontal section and left-hand views are finally run over a second time and the section is cross-hatched as required. It is necessary:

(a) in the frontal section, to show the unsectioned tooth of the driving gear (the pinion in our example) in front of the mating tooth of the other gear;

(b) in the left-hand view, the pitch circle of the gear, and the straight line representing the pitch cone of the pinion are drawn with thin chain (dot-and-dash) lines (Fig. 508).

14. CYLINDRICAL WORM GEARING

Worm gearing (Fig. 509*a*) is used for transmitting rotation between nonparallel, nonintersecting (crossed) shafts. It consists of a worm and a wormgear.

The worm is a screw which can be regarded as a helical gear having helical teeth or threads.

Worm gearing can be classified as:

(a) gearing with a cylindrical worm on which the teeth are located on a cylindrical surface;

(b) gearing with a globoid (also called hourglass, Hindley or cone) worm on which the helical teeth are located on a surface generated by revolving a circular arc about the axis of the worm.

There are various types of cylindrical worms of which the most widely used one is the Archimedean worm. In this worm, the generatrices of the helical surfaces of the threads intersect the worm axis. Consequently, the helical threads (teeth) of the worm are bounded by Archimedean (oblique) helicoids (see Fig. 361*b*).

An axial section of the thread of an Archimedean worm is bounded by straight lines and forms an isosceles trapezoid in which the inclination of the sides is specified by the profile angle α (Fig. 509*b*). Usually, the profile angle is $\alpha = 20°$. Much less frequently employed are involute and convolute worms. These two types of worms have a more complicated profile. The drawing course deals mainly with worm gearing having an Archimedean worm, and with the worm and wormgear axes crossing at an angle of 90°.

With respect to the hand of the threads, worms may be either right- or left-hand; with respect to the number of threads, they may be single-, two-, three- and multiple-start worms.

Applied to a great extent are worms made integral with their shafts. In such worms the root diameter of the worm is near to the shaft diameter.

15. PRINCIPAL PARAMETERS OF WORMS AND WORMGEARS

The axial, or linear, pitch p_x of a worm is the distance along the axis between similar points on adjacent threads (Fig. 509*b*).

The lead p_z of a multiple-start worm is the distance along the axis between similar points on adjacent threads of one of the starts (it is usually defined as the distance the worm ad-

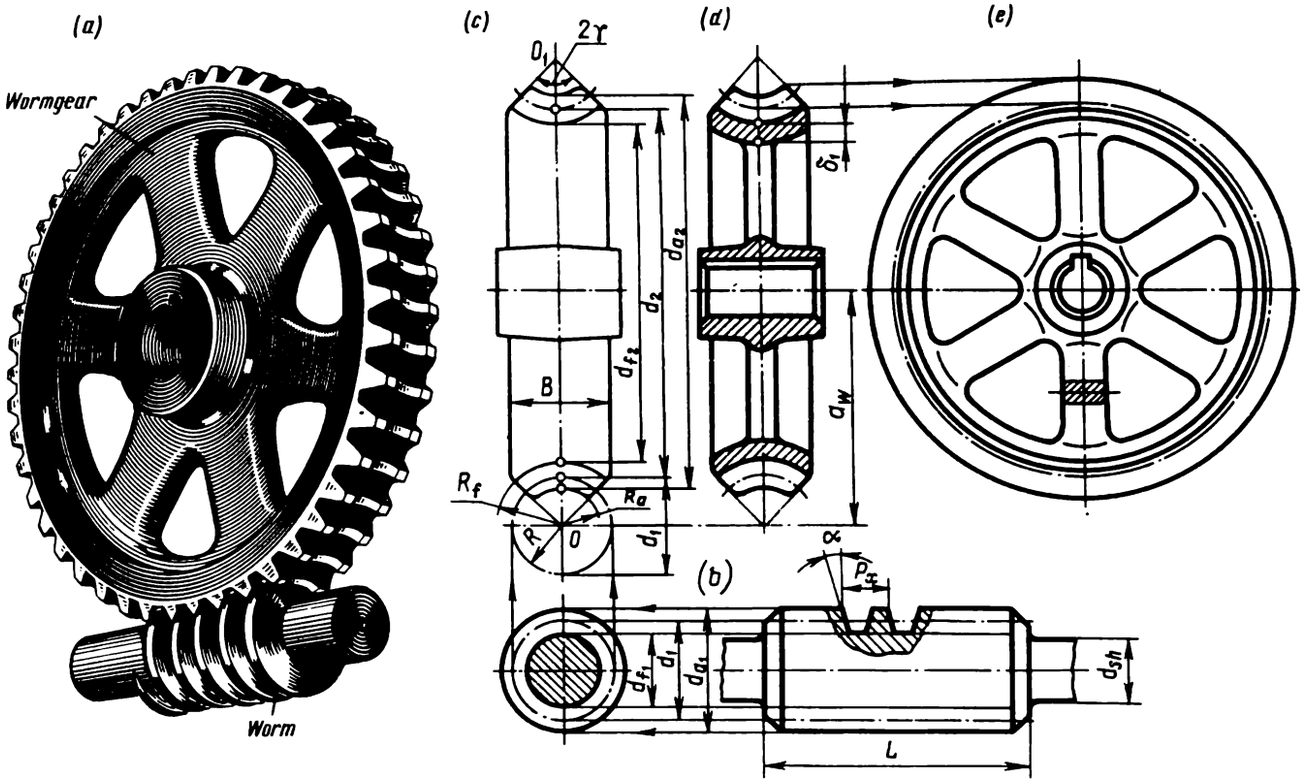


Fig. 509

vances, as a screw, in one complete revolution). The relationship between the axial pitch and the lead, as for any multiple-start screw, is

$$p_z = z_1 p_x$$

where z_1 is the number of starts on the worm.

The axial pitch p_x is related to the axial module by the formula

$$m_x = \frac{p_x}{\pi}$$

The axial module m_x determines the principal parameters of the worm. Module m_x is to be selected from the standard values (see Table 20). Similar to a gear, a worm has a pitch diameter d_1 (Fig. 509*b*). The pitch diameter is taken as a function of the module:

$$d_1 = qm_x$$

Factor q is equal to the number of modules in the pitch diameter.

It is to be selected on the basis of the given axial module, according to the standard (see Table 24).

To exclude designs with too thin worms, the standard provides for an increase of q with a reduction in m_x. The deflection of the worm shaft increases if the worm is of insufficiently large diameter. This impairs proper engagement with the wormgear.

The addendum of the worm thread

$$h_a = m_x$$

The dedendum of the worm thread

$$h_f = 1.2m_x$$

The height of the worm thread

$$h = h_a + h_f = 2.2m_x$$

Taking the worm thread dimensions into account, the other dimensions of the worm can be found (Fig. 509*b*):

Table 24

$q = f(m_x)$

m_x, mm	1	1.5	2	2.5	3	4	5	6	8	10
q	9			8		7			6	

The outside diameter of the worm is $d_{a1}=d_1+2m_x$, and its root diameter, $d_{f1}=d_1-2.4m_x$.

The length L of the threaded portion of the worm depends upon the number of teeth z_2 on the wormgear and is determined by the formula

$$L=(11+0.06z_2)m_x$$

The tops of the teeth on the wormgear lie on the surface of a circular ring obtained by the revolution of a circular arc about the wormgear axis (Fig. 509*c*). The dimensions of the wormgear teeth are specified in the central plane of the toothed rim (plane of symmetry of the rim, perpendicular to the wormgear axis). The module m_t of the wormgear in this plane is known as the circular module and is equal in magnitude to the axial module m_x of the mating worm: $m_t=m_x$.

The height dimensions of the wormgear teeth are equal to those of the worm thread:

addendum, $h_a=m_t$;

dedendum, $h_f=1.2m_t$;

depth of tooth, $h=h_a+h_f=2.2m_t$.

The other dimensions of the wormgear are calculated from the given module m_t and number of teeth z_2:

pitch diameter of the wormgear, $d_2=m_tz_2$;

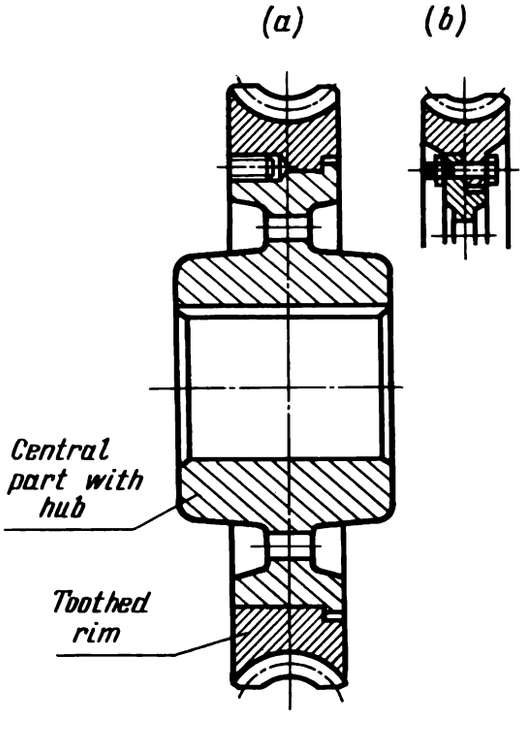


Fig. 510

throat diameter of the wormgear, $d_{a2}=d_2+2h_a=m_t(z_2+2)$;

root diameter of the wormgear, $d_{f2}=d_2-2h_f=m_t(z_2-2.4)$.

In critical high-speed worm gearing, the rim of the wormgear is made of an antifriction material (bronze or brass). If the wormgear is of large diameter, its hub and web are made of cast iron or steel to save expensive nonferrous metal. The toothed rim is secured to the hub or web by means of screws (Fig. 510) or bolts, or in a pressmould when the hub is made of a plastic.

16. DRAWING A WORM AND WORMGEAR COMPRISING A WORM GEARING DRIVE

Drawings of worms and wormgears should comply with the pertinent standard. An example of the construction required in making drawings of a worm and wormgear comprising a wormgear drive is illustrated in Fig. 509*b*, *c*, *d* and *e*. We begin with the following initial data:

(1) modules of the worm and wormgear, $m_x=m_t=2$ mm;

(2) number of starts on the worm, $z_1=1$ (single-start worm);

(3) number of teeth on the wormgear, $z_2=42$;

(4) diameter of the worm shaft, $D_{sh1}=12$ mm;

(5) diameter of the wormgear shaft, $D_{sh2}=16$ mm;

(6) the wormgear is made of steel and is secured on its shaft by a straight key.

The drawings are constructed on the basis of the parameters and elements of the worm and wormgear, determined by calculations.

The keyway dimensions are taken from the standard for a shaft of a diameter $D_{sh2}=16$ mm.

The shape and dimensions of the spokes, if the wormgear is of the spoke type, are commonly given.

In the left-hand view, the pitch circle is described with a thin chain (dot-and-dash) line.

17. TRAINING DETAIL DRAWING OF A WORMGEAR

The detail (working) drawings of cylindrical worms and their mating wormgears should comply with the pertinent drawing standard. The views on these drawings are to be made according to the example illustrated in Fig. 509*b*, *d* and *e*.

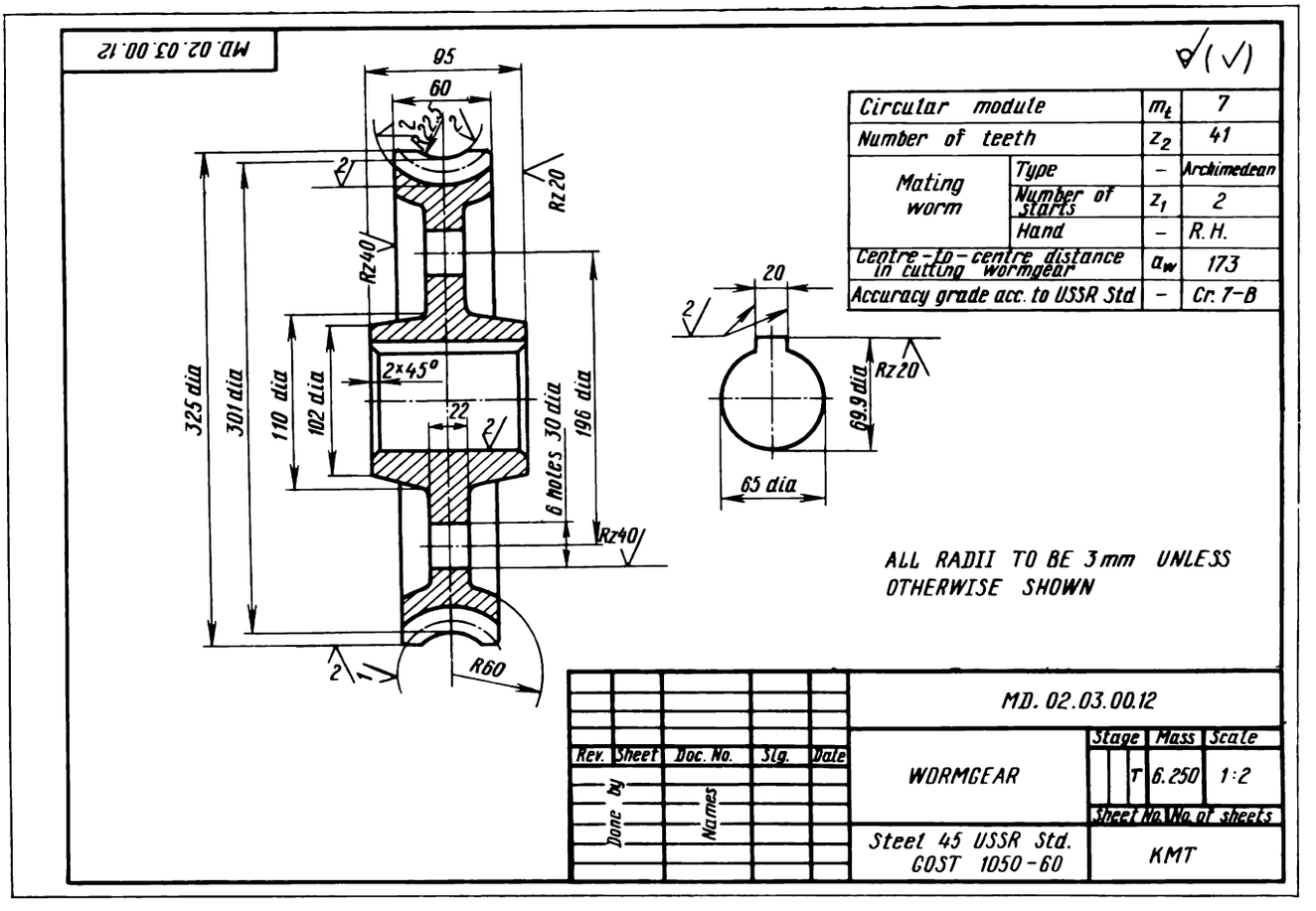


Fig. 511

In the detail drawing of a wormgear (Fig. 511), the frontal section fully specifies the design of the part so that no left-hand view is required.

The dimensions shown in the detail drawing of a wormgear include:

(a) throat diameter, i.e., the addendum circle diameter in the middle plane of the wormgear;

(b) outside diameter, i.e., the maximum diameter of the toothed rim;

(c) face width of the wormgear;

(d) dimensions specifying the external outline of the toothed rim, such as: throat radius (radius of the concave face of the wormgear), edge round radii or chamfers at the end faces, gear face angle, etc.;

(e) other dimensions concerning the hub, web and other elements of the wormgear.

The symbol for the maximum permissible roughness of the side surfaces of the teeth is shown on the circular arc described with a thin chain (dot-and-dash) line on the teeth in the section and representing the pitch circle of the mating worm.

The wormgear engages the worm. Therefore, the parameters of the mating worm and of the wormgear drive are taken into account in manufacturing the wormgear. For this purpose, the table on the drawing lists information about the mating worm and the centre distance.

18. TRAINING DETAIL DRAWING OF A CYLINDRICAL WORM

The detail drawing of a worm (Fig. 512) consists of the main view and the necessary sectional views. The axis of the worm is drawn parallel to the title block. A broken-out section is made on the main view to show the profile of the worm thread in an axial plane.

The drawing of the worm indicates:

(a) outside diameter of the worm;

(b) length of the threaded portion of the worm;

(c) edge round radii or chamfers at the ends of the outside (addendum) cylinder;

(d) edge round and fillet radii of the thread;

(e) other dimensions determining the design elements of the worm;

(f) maximum permissible roughness of the side surfaces (profile), top and root surfaces of the threads, and of all the other surfaces.

The table of parameters given on training drawings (Fig. 512) lists the principal data required to manufacture the worm.

The helix angle of the threads at the pitch cylinder, given in the table, is determined from its tangent:

$$\tan\beta=\frac{p_z}{\pi d_1} \quad \text{or} \quad \tan\beta=\frac{z_1}{q}$$

where the lead of the threads (axial pitch of the helix), $p_z=p_x z_1=\pi m_x z_1$, and the number of modules in the pitch diameter, $q=\frac{d_1}{m_x}$.

19. MAKING SKETCHES FROM A WORM AND A WORMGEAR

In making a sketch or drawing from a finished worm and wormgear, it is necessary to determine their modules (or module if they are mating items).

The axial module of the worm is approximately determined as follows:

(1) a portion of the worm, of length l, is measured between similar points on the threads (the distance l should be measured between the threads of the same start for a multiple-start worm);

(2) the number n of axial pitches in the length l is counted;

(3) the axial pitch is determined by the formula: $p_x=\frac{l}{n}$;

(4) the axial module is determined by the formula: $m_x=\frac{p_x}{\pi}$.

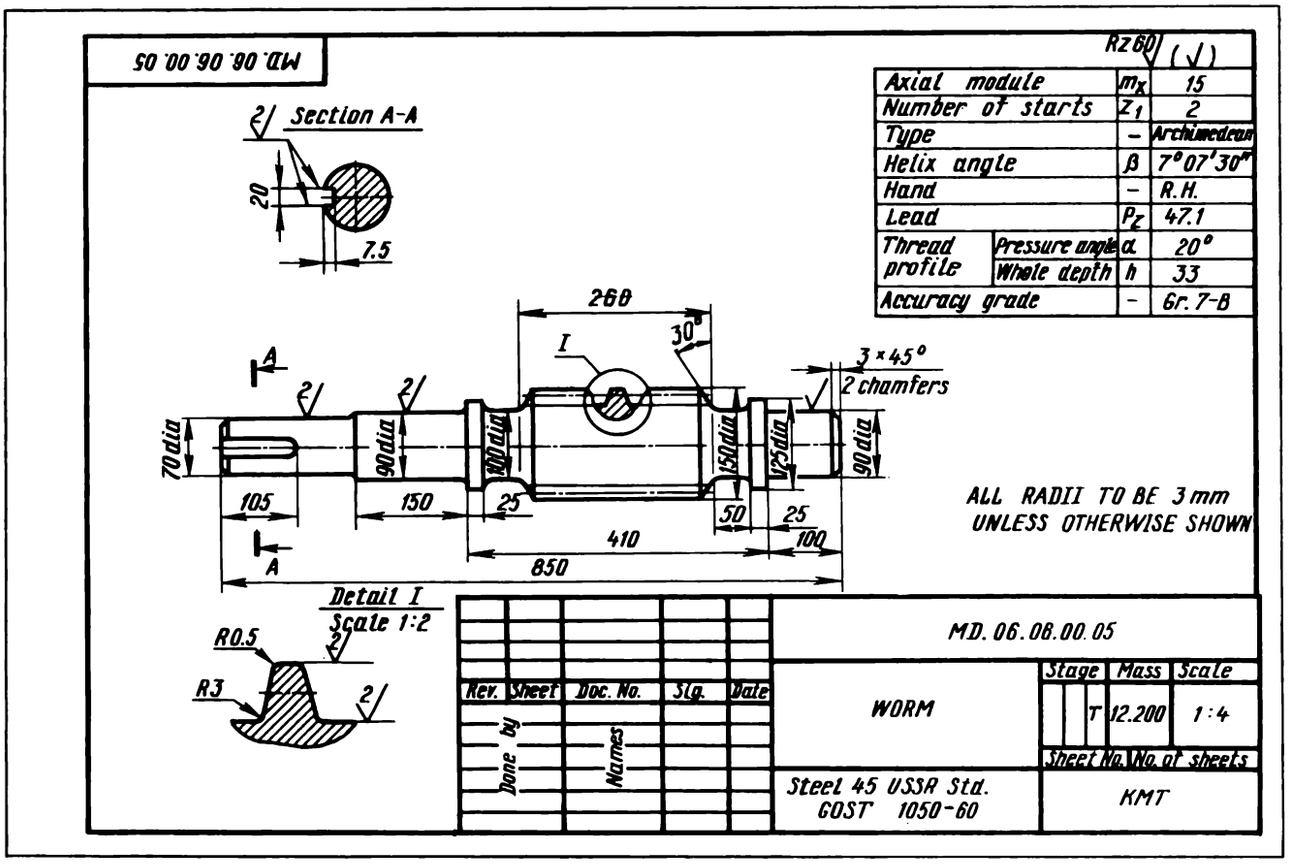


Fig. 512

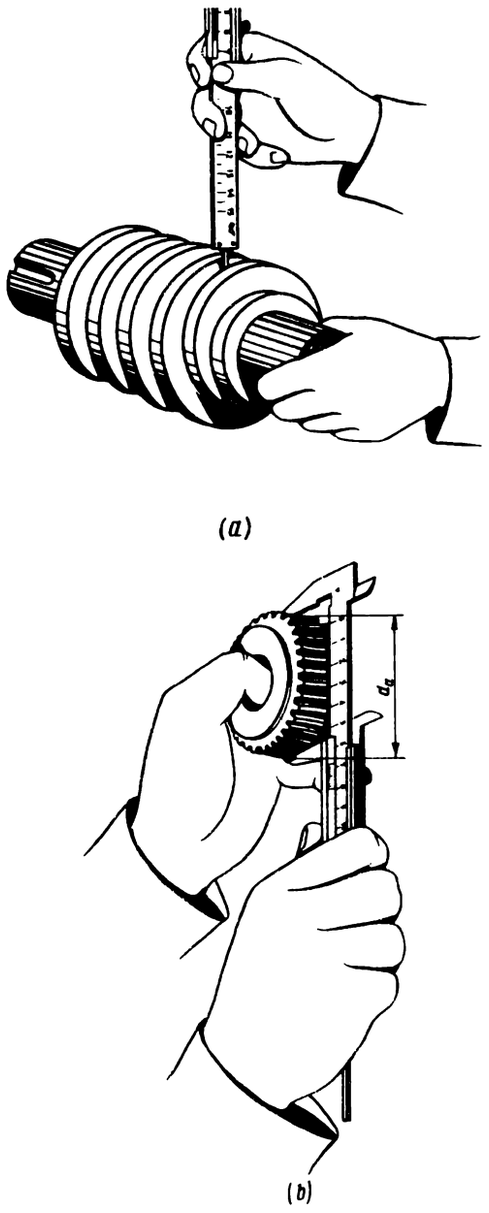


Fig. 513

To determine the circular module m_t of the wormgear, the number of teeth z_2 is counted, and the throat diameter d_{a2} measured (see Fig. 513*b*). Then the circular module is calculated:

$$m_t = \frac{d_{a2}}{z_2 + 2}$$

The calculated values of the modules m_x and m_t are to be rounded off to the nearest standard values (see Table 20). If the worm and wormgear are mating items, the values of m_x and m_t should obviously be equal.

Another way to find the axial module is to measure the height h of the thread on the worm with a depth gauge (Fig. 513*a*). It should be equal to the depth of tooth on the mating wormgear. Since the depth of tooth

$$h = 2.2m_x$$

the axial module is

$$m_x = \frac{h}{2.2}$$

All the other parameters and dimensions of the elements of the worm and wormgear are determined by making measurements and the necessary calculations. The views are constructed similarly to the examples illustrated in Fig. 509. The sketches or detail drawings are made by analogy with the examples of Figs. 511 and 512.

20. DRAWING WORM GEARING

Worm gearing drawings should comply with the stipulations of the pertinent drawing standard.

Figure 514 illustrates the construction of the worm gearing of the reducing gear unit shown in Fig. 514*a*. The drawing (Fig. 514*c*) shows only the relative positions of the worm and wormgear in the reducing gear (Fig. 514*b*) without taking into account the other parts of the latter.

To construct a drawing of worm gearing, it is necessary to have data characterizing this drive: the axial module m_x of the worm and the circular module m_t of the wormgear, the number of starts, z_1, of the worm, the number of teeth, z_2, on the wormgear, etc.

All the data required for the construction are commonly obtained by calculations or by measurements of the finished items.

The construction of the worm and wormgear is shown in sufficient detail in Fig. 509.

A drawing of the worm gearing is made in the following order (Fig. 514*c* and *d*):

1. To construct the frontal section, the centre distance, $a_w = 0.5(d_1 + d_2)$, is calculated and laid off.

2. Circles and circular arcs of radii R_1, R_2, R_3, R_4, and R_5 are described. They determine the boundaries of the pitch surfaces and the outside and root surfaces of the threads and teeth on the worm and wormgear.

3. The left-hand view is constructed by projecting points along horizontal lines in the direction of the arrows. Shown in this view are the rolling circle of the wormgear and the generatrix of the rolling cylinder of the worm; these should

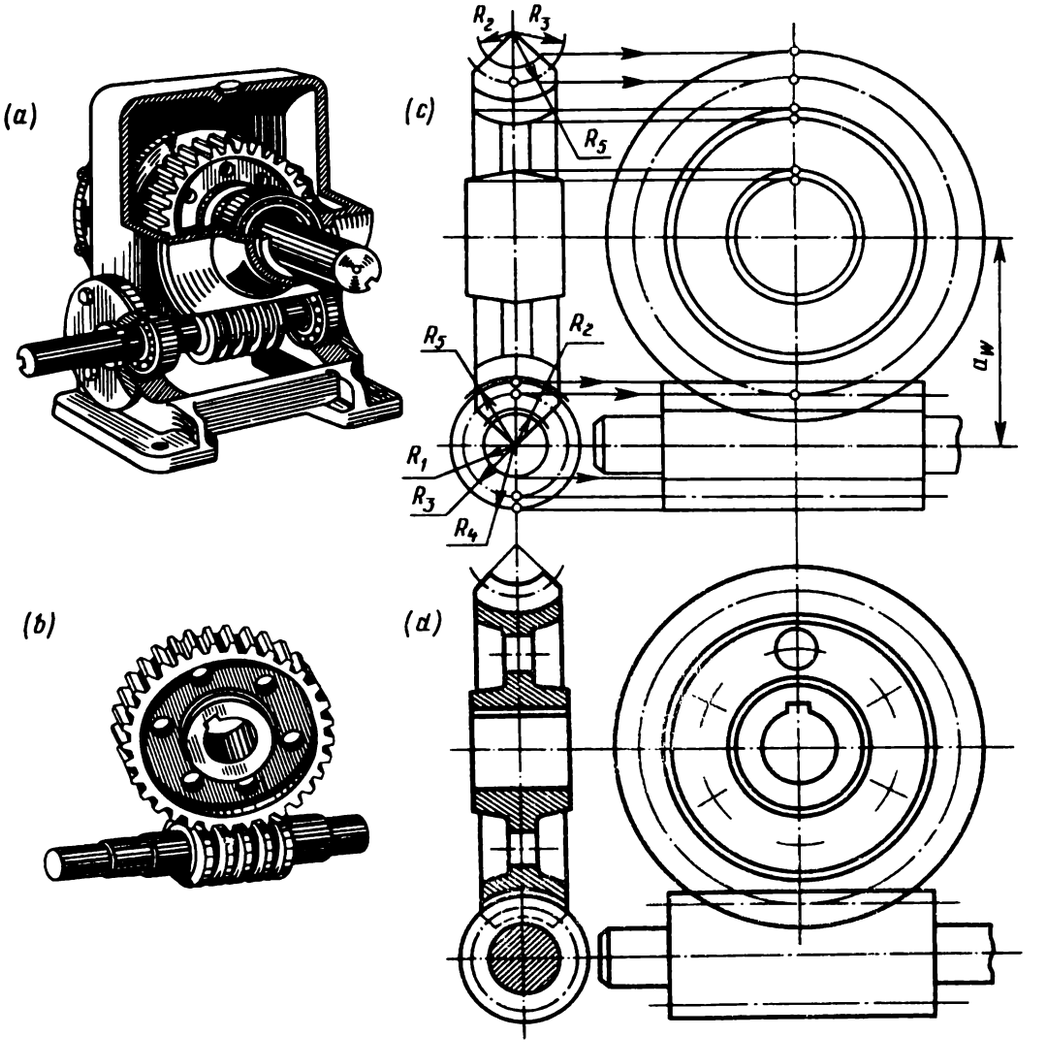


Fig. 514

be tangent to each other. The outlines of the other elements of the gearing are determined.

4. The finished drawing of the worm gearing is shown in Fig. 514*d*. In the axial section of the wormgear, the thread of the worm is shown in front of the mating tooth of the wormgear.

In the left-hand view, the outside circle of the wormgear and the outside cylinder of the worm are described with thick continuous lines intersecting in the zone of engagement.

21. TYPES OF GEARING AND THEIR ELEMENTS

In addition to spur and bevel gears, gears of other shapes and with other tooth profiles may be used in certain cases.

In an internal gear (Fig. 515), the addendum circle (also called inside circle) is inside the root circle. The parameters of these gears are cal-

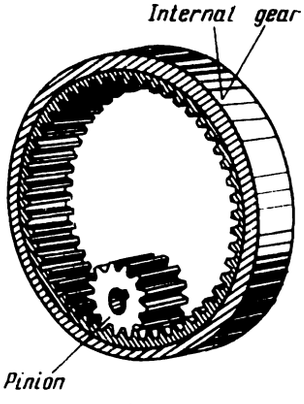


Fig. 515

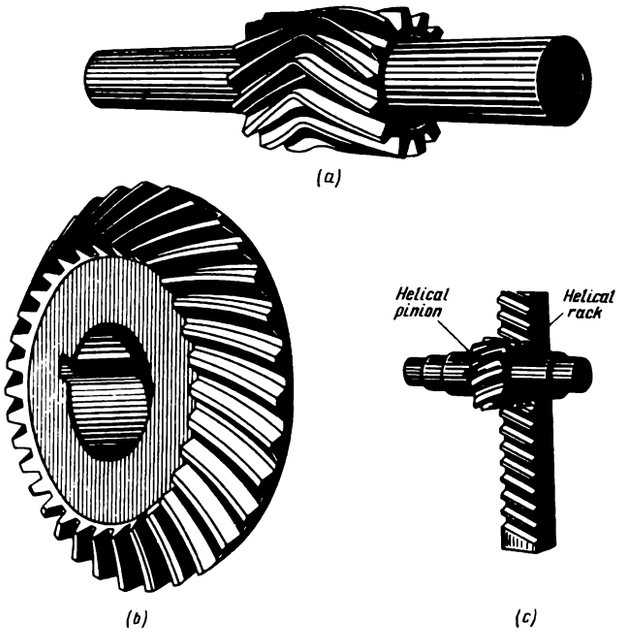


Fig. 516

culated, and their drawings are made in the same way as for external gears (see Sec. 3). It is necessary to take into account the fact that on the drawing of an external gear the addendum is laid off radially from the pitch circle in the direction from the centre toward the periphery. For internal gears, on the contrary, it is laid off in the direction from the periphery toward the centre.

In many cases, helical gears are used rather than spur gears (Fig. 516*c*). These gears have teeth of a helicoidal shape located on a cylinder. Helical teeth may be either right- or left-hand and have a helix angle β measured on the pitch cylinder.

In calculations of helical gears, distinction is made between the circular pitch $\widehat{p}_t$ and the normal pitch p_n, which correspond to the circular module $m_t=\frac{\widehat{p}_t}{\pi}$ and the normal module $m_n=\frac{p_n}{\pi}$.

A development of the pitch cylinder of a helical gear is shown in Fig. 517. It clearly shows the direction of the teeth and the helix angle β of the gear.

The circular pitch $\widehat{p}_t$ is measured in a section perpendicular to the axis of the gear. The normal pitch p_n is measured in a direction perpendicular to the direction of the helical teeth.

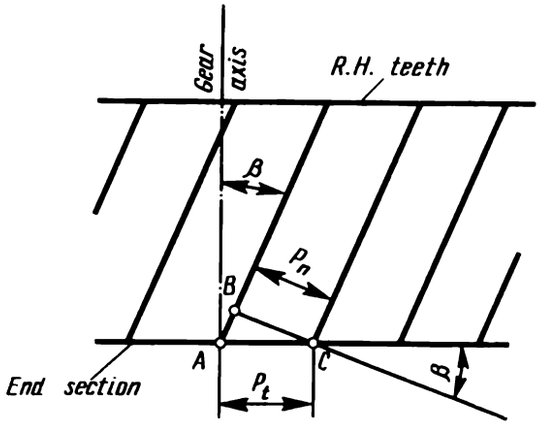


Fig. 517

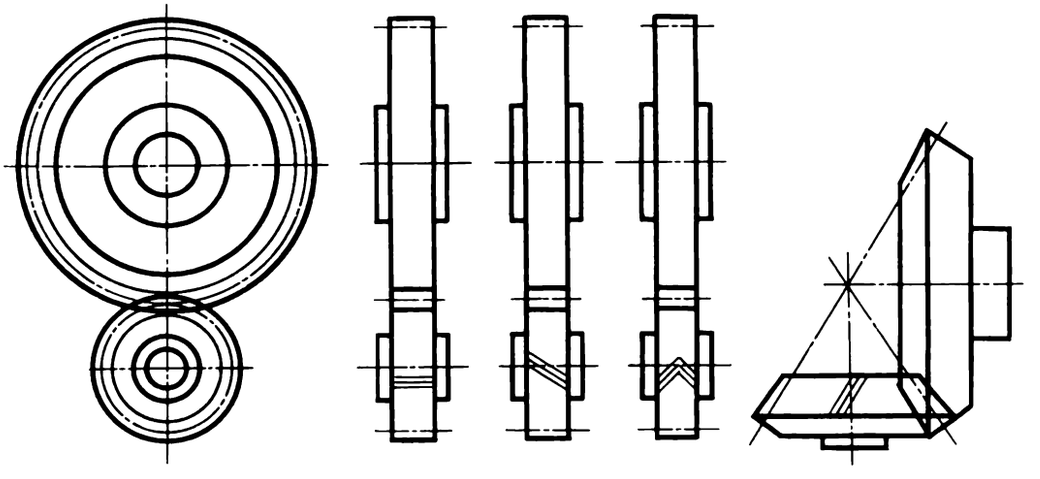


Fig. 518

The relationship between the circular and normal pitches is found from triangle ABC:

$$\overline{BC}=\overline{AC}\cos\beta \quad \text{or} \quad p_n=\widehat{p}_t\cos\beta$$

Dividing both members of the second equation by π, we obtain

$$m_n=m_t\cos\beta$$

Herringbone gears (Fig. 516*a*) can be regarded as two helical gears of opposite hand.

In addition to straight bevel gears, skew bevel gears and curved-tooth (spiral) bevel gears (Fig. 516*b*) are frequently employed.

If the direction of the teeth is to be shown on gearing drawings, then three thin continuous lines inclined in the proper direction are shown on one of the mating gears near to its axis (Fig. 518).

22. RATCHET GEARING

Ratchet gearing may be used to keep a shaft rotating only in one direction (Fig. 519*a*). More often it is used to transmit intermittent rotation. Such gearing (or mechanism) consists of two main components: the ratchet wheel and the pawl (Fig. 519*b*). The end of the pawl, engaging the tooth space of the ratchet wheel, prevents the reverse rotation of the shaft on which the wheel is mounted.

The shape of a ratchet wheel tooth (Fig. 519) is entirely different from the profile of gears. The working face of the ratchet teeth is inclined at an angle $\beta=12°$ to $15°$ to the radius of the wheel. The magnitude of this face angle and the position of the pawl axis is selected so that the pawl drops freely into the tooth space and cannot leave it unintentionally.

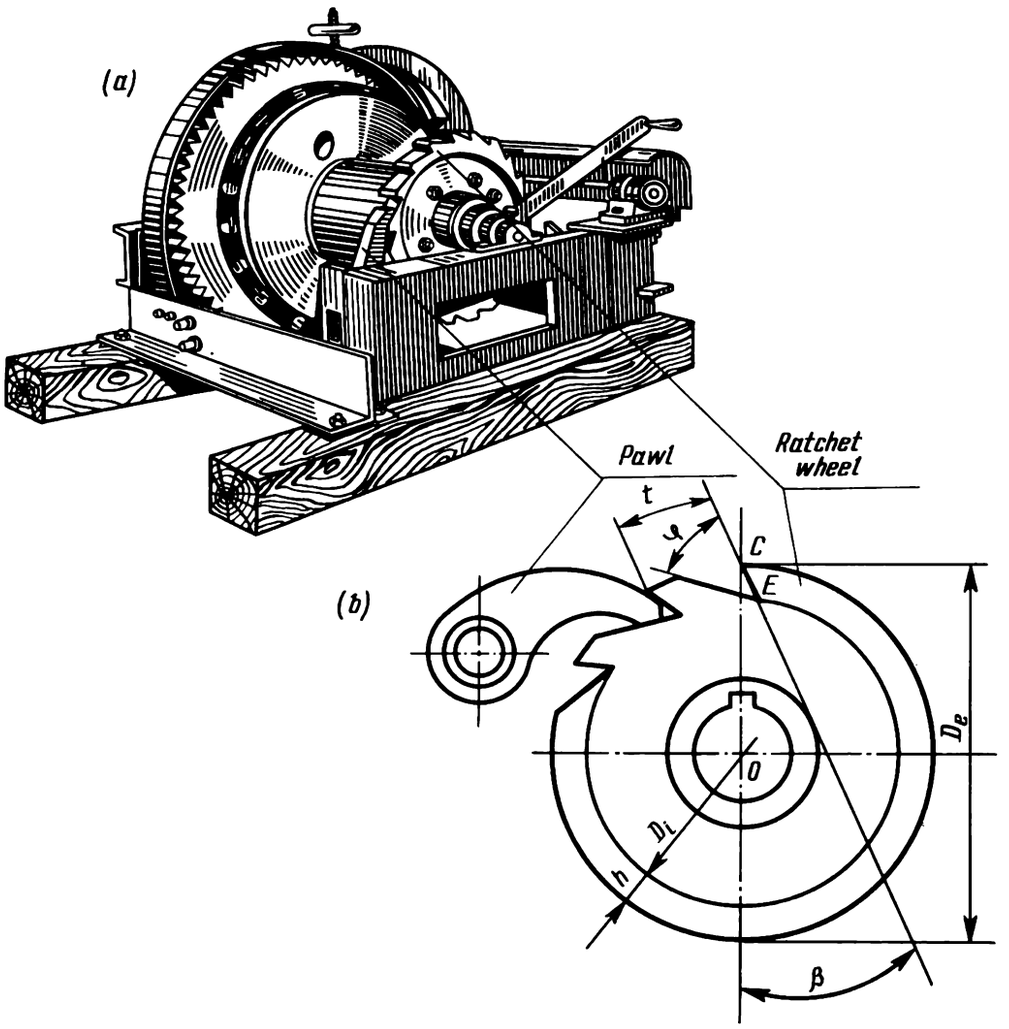


Fig. 519

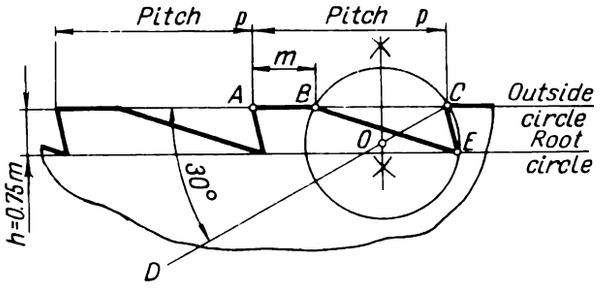


Fig. 520

Similar to toothed gears, a ratchet wheel has a module

$$m=\frac{p}{\pi}$$

where p is the circular pitch, or the distance between the adjacent teeth measured along the outside circle.

The following relationships enable all the dimensions of a ratchet gear to be determined.

The tooth depth is

$$h=0.75m$$

The diameter of the outside circle is

$$d_a=mz$$

where z is the number of teeth on the ratchet wheel.

The diameter of the root circle is

$$d_f=d_a-2h=m(z-1.5)$$

Angle φ is taken from 55° to 60°.

The drawing of a ratchet wheel is simplified; only one or two teeth are shown. The root circle is shown with a thin continuous line (Fig. 519).

Now construct the profile of a ratchet tooth given the angle (60°) between the working and

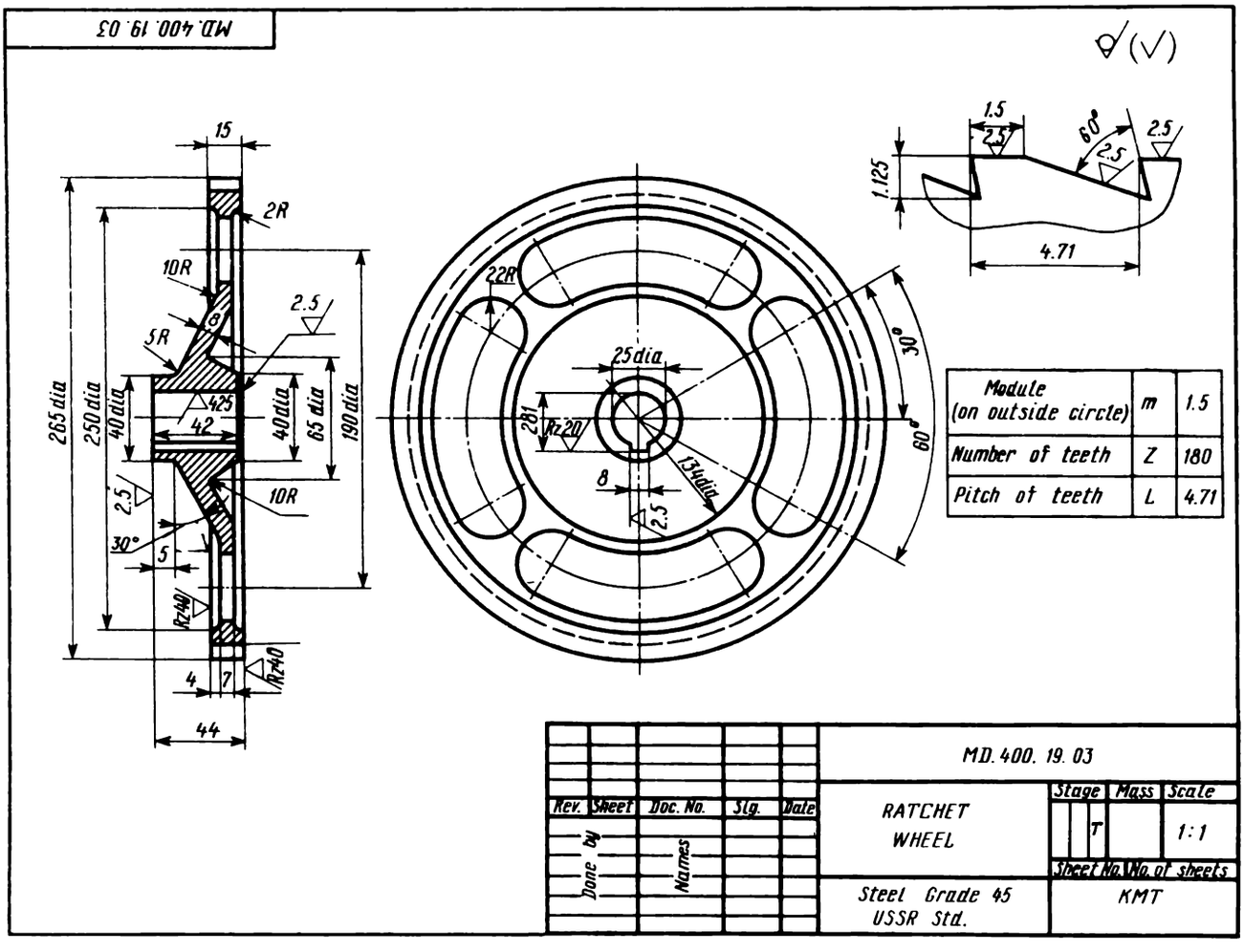


Fig. 521

inclined faces of the tooth, module $m=1.5$ mm, number of teeth $z=180$ (Fig. 520). To do this:

1. Describe the outside circle of diameter

$$d_a=mz=1.5\times 180=270 \text{ mm}$$

2. Describe the root circle of diameter

$$d_f=d_a-2h$$

where $h=0.75m=0.75\times 1.5=1.125$ mm.

Hence

$$d_f=270-2\times 1.125$$
$$=270-2.25=267.75 \text{ mm}$$

3. Mark off several tooth pitches on the outside circle

$$p=\pi m=3.14\times 1.5=4.71 \text{ mm}$$

4. From the points of division lay off a chord length *AB* equal to the module *m* which will be the tooth length measured along the outside circle.

5. Construct an angle of 30° *(BCD)* on the chord *BC* with the point *C* as a vertex.

6. Erect a perpendicular at the midpoint of the chord *BC* to intersect *CD* at the point *O*.

7. From *O* as a centre and with a radius equal to *OC* describe an arc which will intersect the root circle at the point *E*.

8. Join the points *C* and *E* with a straight line which will represent the working face of the tooth against which the pawl bears.

9. Join the points *B* and *E* with a straight line to obtain the inclined portion of the tooth profile along which the pawl slides during reverse rotation of the ratchet wheel.

A working drawing of a toothed wheel of a ratchet gear feeding warp into an automatic loom is represented in Fig. 521. The side view shows only four teeth, the tooth profile being drawn separately as a removed element, scaled up and adequately dimensioned. The cutting information is tabulated.

This ratchet wheel with a large number of teeth ensures a small angle through which the shaft rotates per swing of the pawl, and this provides a uniform feed.

As is seen from the title block, the ratchet is made of high-strength cast iron, grade BЧ 45-5.

23. CHAIN DRIVES

A chain drive (Fig. 522) has two toothed wheels called sprockets. The sprockets are keyed to their shafts. Rotation is transmitted from one shaft to the other by a power transmission chain running over and engaging the sprockets.

Many types of power transmission chains are employed in engineering. Most widely used are roller chains (Fig. 523) which, like most other types of chains, have been standardized.

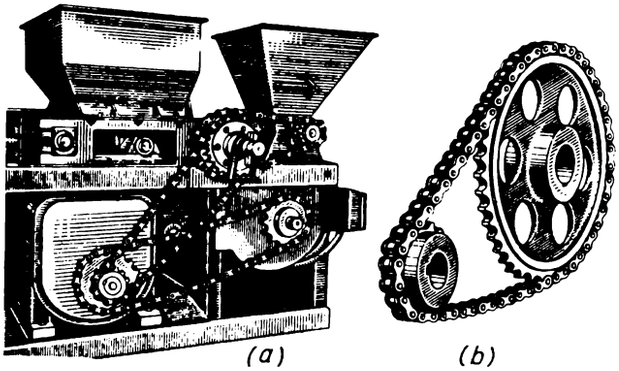


Fig. 522

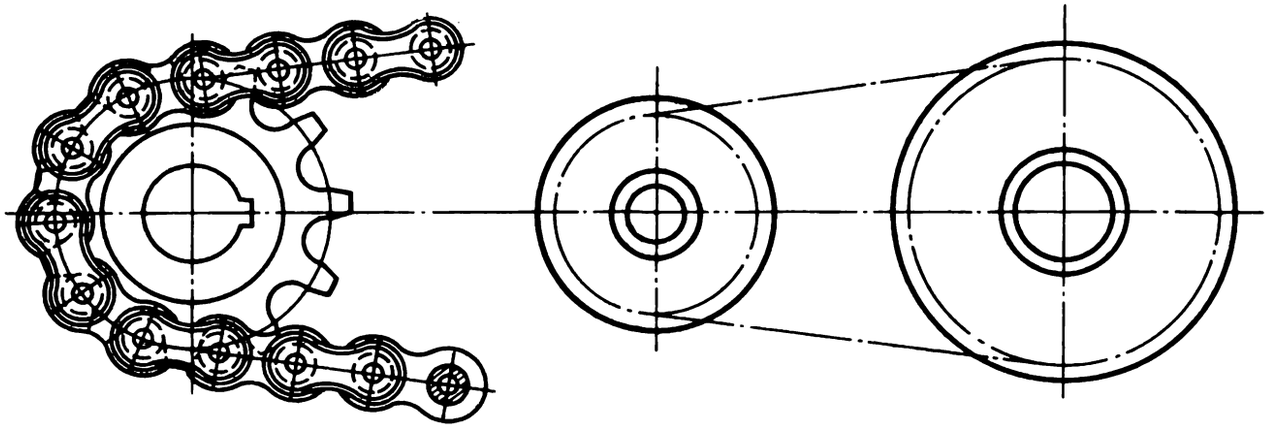


Fig. 523

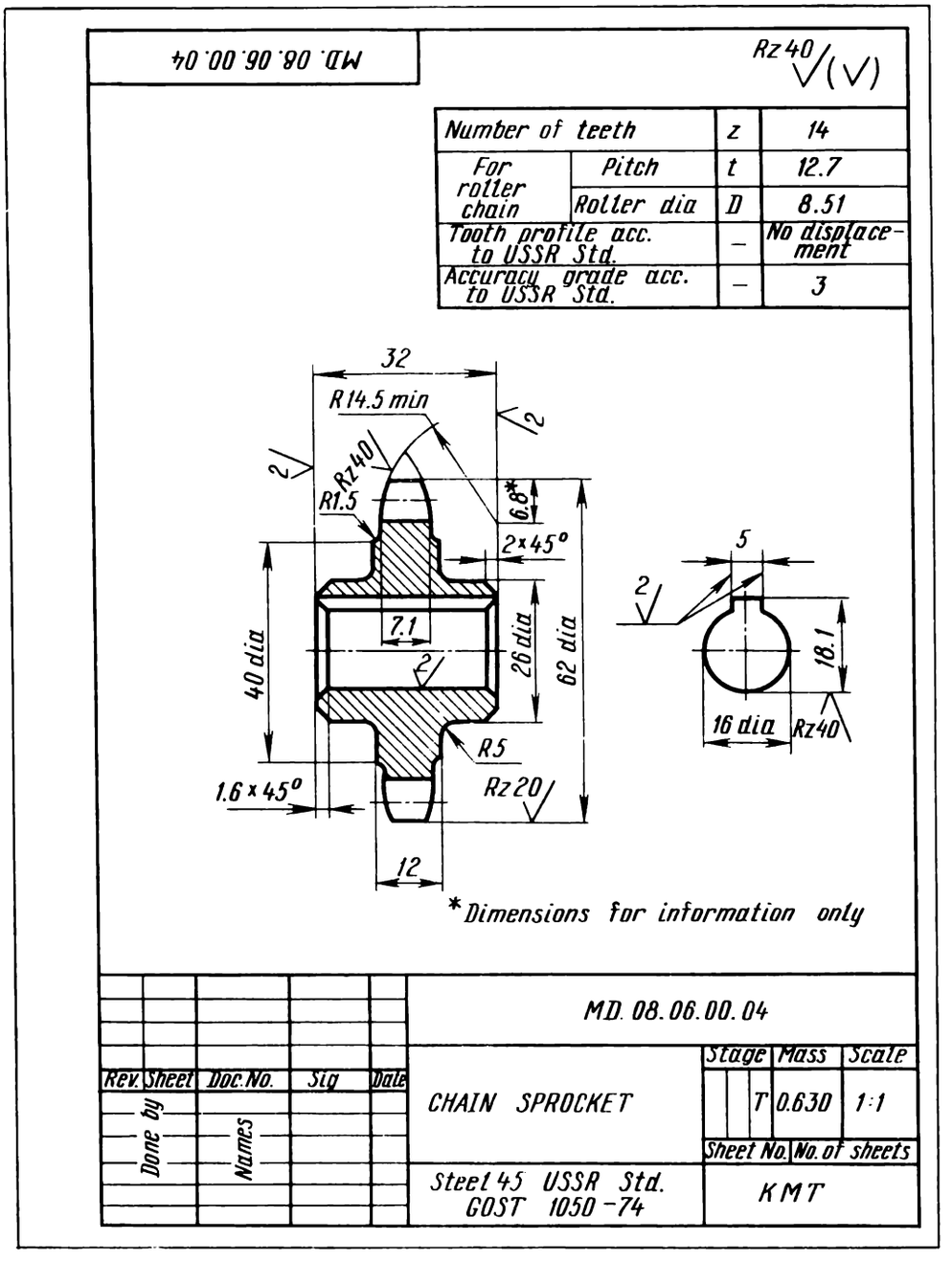


Fig. 524

The profiles of sprocket teeth (Fig. 523) differ from those of gears. They consist of two circular arcs whose radii are specified in the standards.

According to the pertinent drawing standard, chains are shown in the drawings of chain drives by thin chain (dot-and-dash) lines that connect the pitch circles of the sprockets.

A special standard covers the drawings of chain sprockets. An example of a drawing for a roller chain sprocket is shown in Fig. 524. It is simplified to some extent as is regular practice in a drawing course.

The drawing indicates:

(a) width of the teeth;

(b) radius of the teeth in the longitudinal section;

(c) distance from the top of the teeth to the line of centres of the teeth radii in the longitudinal section;
(d) maximum diameter of the hub flange below the toothed rim;
(e) fillet radii of the hub flange at the toothed rim and at the hub;
(f) outside diameter of the sprocket;
(g) other dimensions determining the design of the sprocket;
(h) maximum permissible surface roughness.
The information necessary for manufacturing the sprocket is listed in the table.

Questions

1. What types of drives are employed in mechanical engineering?
2. What is called the module of toothed gearing?
3. What are the relationships between the module, the number of teeth, and the pitch diameter of gears?
4. What are the conventions adopted in representing the teeth of gears?
5. How is the direction of the teeth shown on the drawings of helical and herringbone gears?
6. What kinds of lines are used to draw the rolling, pitch, root, and outside circles of gears?

Exercise 75

Make a drawing of an external spur gear drive as assigned from Fig. 501.

Exercise 76

Make a drawing of a bevel gear drive as assigned from Fig. 503.

Exercise 77

Make a drawing of a worm gear drive as assigned from Fig. 514.

CHAPTER 7

MAKING, READING AND DETAILING TRAINING ASSEMBLY DRAWINGS

1. SET OF DESIGN DOCUMENTS

Depending upon the stage of design, designing documentation, including drawings and other records, may be divided into the project and working documents. A set of project documents provides comprehensive information on the product being designed and serves as the basis for making the working documentation.

In the Mechanical Drawing course, the student usually deals with working documentation (drawings) which includes assembly drawings, detail drawings, parts lists and diagrams.

The *assembly drawing* is a design document containing a representation of the product and all the other data required for its assembly (manufacture).

The *detail drawing* is a design document containing all the information required to manufacture the part depicted.

The *parts list* is a tabulated statement specifying the component parts and units of the product. It is to be drawn on separate sheets of size 11 as shown in Fig. 525.

It is permissible for training drawings to place the parts list directly on the assembly drawing. If there are a great number of components, the parts list may require several sheets. The first sheet should have the title block shown in Fig. 525, while the subsequent sheets have the narrow strip title illustrated in Fig. 526. Each sheet of the parts list should be drawn and filled in as shown in Figs. 525 and 526.

In the general case, a parts list consists of sections which should be arranged in the following order:

Documentation,
Integrated systems,
Assembly Units,
Parts,
Standard Items,
Materials,
Sets.

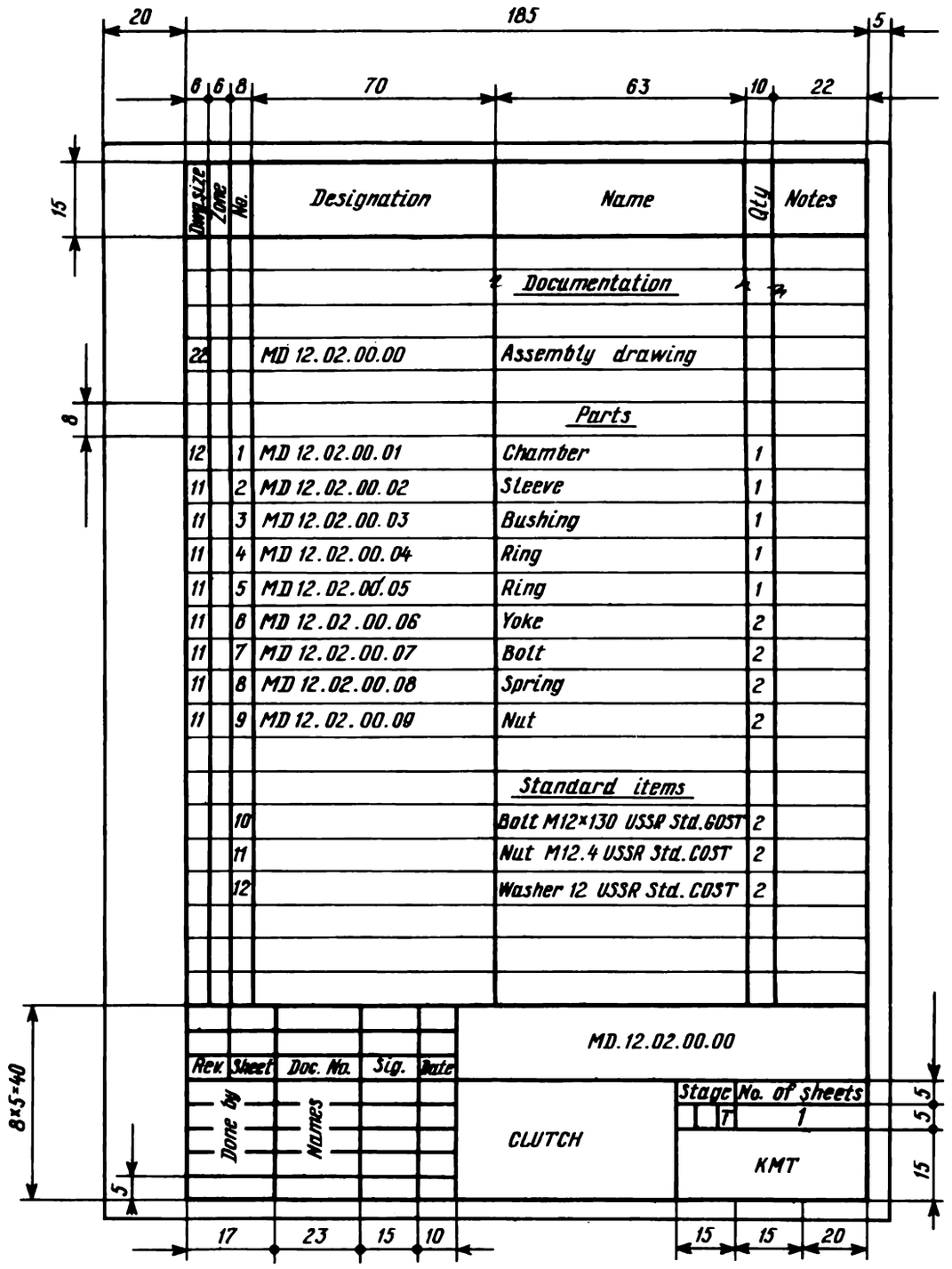

20
185
5
6
6
8
70
63
10
22
15
Dwg size
Zone
No.
Designation
Name
Qty
Notes
Documentation
MD 12.02.00.00
Assembly drawing
8
Parts
MD 12.02.00.01
Chamber
MD 12.02.00.02
Sleeve
MD 12.02.00.03
Bushing
MD 12.02.00.04
Ring
MD 12.02.00.05
Ring
MD 12.02.00.06
Yoke
MD 12.02.00.07
Bolt
MD 12.02.00.08
Spring
MD 12.02.00.09
Nut
Standard items
Bolt M12×130 USSR Std.GOST
Nut M12.4 USSR Std.COST
Washer 12 USSR Std.COST
MD.12.02.00.00
Rev.
Sheet
Doc. No.
Sig.
Date
Done by
Names
CLUTCH
Stage
No. of sheets
1
KMT
8×5=40
5
5
5
15
17
23
15
10
15
15
20

Fig. 525

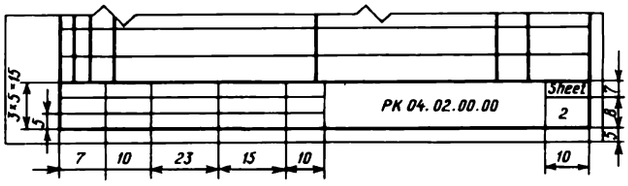


Fig. 526

The parts list, depending upon the composition of the product, may, or may not, contain all these sections. In the Mechanical Drawing course, parts lists usually have from 3 to 5 sections: Documentation, Assembly Units, Parts, Standard Items, and Materials.

The name of each section is written in the form of a title in the "Name" column and is underlined. Before and after the name of each section one space is left free. Several spaces are to be left free following each section so that additional entries can be made.

The following information is to be written into the "Name" column:

(a) in the "Documentation" section, the draughtsman writes the name of the document, for example: "Assembly Drawing", "Outline Assembly Drawing", "Explanatory Report", "Manufacturing Specifications", etc.;

(b) indicated in the "Assembly Units" section are the names of the assembly units which are directly parts of the product assembly drawing;

(c) the "Parts" sections lists all the parts of the product;

(d) the "Standard Items" section lists the designation of all the standard parts in accordance with the pertinent standards.

The material of which each part is to be made is specified in the detail drawing of the part. In the "Materials" section, the material is specified only for parts for which no detail drawings are made, for instance, parts made of wire, gasket material, packing, etc.

The "Designation" column lists the conventional designations given at the manufacturing plant to the various components of the product (assembly units, parts, etc.). Simplified designations are used in training drawings, and the "Standard Items" and "Materials" sections have no designation.

The ordinal number of the components of the product are listed in the "No." column (see Fig. 558).

The column "Dwg. size" indicates the designation of the sheet size of the design document. For parts which do not require drawings, the abbreviation *ND* (no drawing) is indicated.

The column "Zone" is used on large drawings to indicate the zone of the drawing in which the component part of the product is located.

2. TRAINING ASSEMBLY DRAWINGS

The training assembly drawings made in the Drawing course differ from the drawings used in regular production which contain substantially more graphical details and notes. Training assembly drawings are made from the sketches of the parts of a finished article (such training assembly drawings are also made use of in covering the topic "Reading and Detailing Assembly Drawings").

Illustrated in Fig. 557 is a training assembly drawing which is listed in a "Documentation" section of the parts list given on the drawing itself.

This assembly drawing is to be used for assembling an item called the "Guide Pulley", and for making the detail drawings and assembly unit drawings.

Detailed rules for making assembly drawings are given in the drawing standards of many countries. Presented below are the most important of these rules applicable to drawings made in the Mechanical Drawing course.

An assembly drawing should contain: (1) a representation of the assembly unit, giving an idea of the location and relative positions of the components which are to be joined together according to the given drawing; (2) information enabling the assembly unit to be assembled and checked; (3) dimensions, their tolerance limits, and other parameters and/or requirements which should be checked or satisfied in accordance with the assembly drawing; (4) specifications on the nature of fits and the methods for obtaining them, if the accuracy of the fits is provided for during assembly (selective assembly of the components, fitting, etc.); (5) data on the permanent joints and the methods of their manufacture (welding, brazing, soldering, etc.); (6) ordinal numbers of the components included in the assembly unit; (7) principal specifications or characteristics of the product; (8) overall dimensions determining the maximum external or internal outline of the product; (9) erection or

installation dimensions used to erect or install the product at its site of operation; (10) connecting dimensions required to join the unit to other units or products; (11) all the dimensions necessary for information purposes.

It is permissible to include in the assembly drawing data on the performance of the product and the interaction of its components. Consequently, training assembly drawings frequently contain data and diagrams that explain the design and principle of operation of the product, for example:

(1) symbols of the fits* for critical joints;

(2) arrows showing the direction of rotation of shafts;

(3) module, number of teeth, helix angle, and hand of gear teeth;

(4) pitch diameters of gears;

(5) centre distances of gearings;

(6) left-hand threads *(LH);*

(7) designation of threads (especially if they are not metric threads);

(8) drawing of the profile of special threads, shown in a broken-out section, etc.

In representing the item in an assembly drawing, section views can be drawn to explain the shape and relative position of the component parts.

As a rule in assembly drawings the views are proper projections of one another. This simplifies the reading of the drawing. Certain additional views may be located in the free space of the drawing.

An assembly drawing has the same name as that written into the parts list (Fig. 557). The designation of the assembly drawing is identical to that in the parts list except that it is followed by the letters "*AD*" ("Assembly Drawing").

The ordinal numbers of the components of the assembly unit are indicated in the parts list. In the assembly drawing, the components have the same numbers.

In the assembly drawing, the component numbers are indicated on the horizontal extensions of the leaders drawn from the drawings of the components. The leaders should cross the contour line of the component and end in a dot. The component numbers should be shown in the view in which the component is drawn with visible lines. Leaders should never intersect, they should not be parallel to hatching lines, and, if possible, should not intersect other components or dimensional lines of the drawing (Fig. 558).

As a rule, the component numbers are shown only a single time in a drawing. They may be repeated to indicate identical components.

The component numbers are written parallel to the title block and grouped into a column or line, i.e., in a vertical or horizontal straight line.

The size of the figures of the component numbers should be one or two sizes larger than that of the dimension figures.

It is permissible to draw a single leader for a group of fasteners holding the same joint. In this case, the horizontal extensions should be arranged in a column and connected by a thin vertical line.

The parts list of the item "Guide Pulley" (Fig. 557) contains the section "Assembly Unit" with the entry "Pulley" having the designation *PK* 02.06.01.00. This indicates that a separate parts list and a separate assembly drawing are drawn for the pulley (Fig. 556). Since this assembly drawing is drawn on a sheet of Size 11, the parts list can be placed on the drawing itself, according to the USSR drawing standards. Here, the letters "*AD*" do not follow the designation of the assembly drawing.

It may prove necessary in an assembly drawing to depict various joints obtained by making use of standard fasteners, keys or splines, as well as joints held by pins, or riveted, welded and other permanent joints. Besides, various drives may also need to be shown in an assembly drawing. The following concerns the representation of certain typical items and devices in assembly drawings.

3. LOCKING DEVICES IN ASSEMBLY DRAWINGS

Threaded items subject in operation to vibrations, jerks and blows, are shown in assembly drawings together with the locking devices that prevent them from working loose.

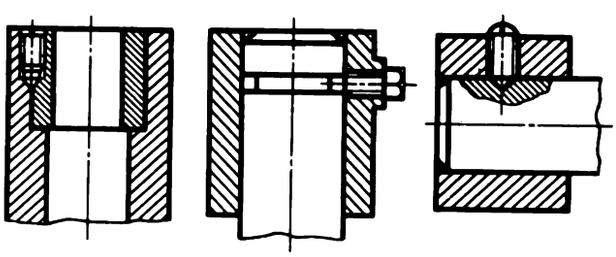


Fig. 527

* See Sec. 13.

Devices intended for locking threaded items are standard and should be drawn to the dimensions listed in the pertinent standards.

Set screws are extensively employed to locate and fasten components with respect to each other. The most widely applied types of set screws and examples of their application are illustrated in Fig. 527.

Set screw designs are stipulated by the pertinent standards.

4. PACKING DEVICES IN ASSEMBLY DRAWINGS

Joints subject to above-atmospheric pressure of some medium should be sealed off by some kind of packing.

Face seals between the end faces of joined components are usually of the gasket type, stamped by a die or simply cut out of the corresponding sheet material (Fig. 528*a*). The outlines of the gasket depend upon the outlines of the joint surfaces to be sealed. Face seals, or gaskets, are placed under covers, between flanges, and in the bodies of various types of valves.

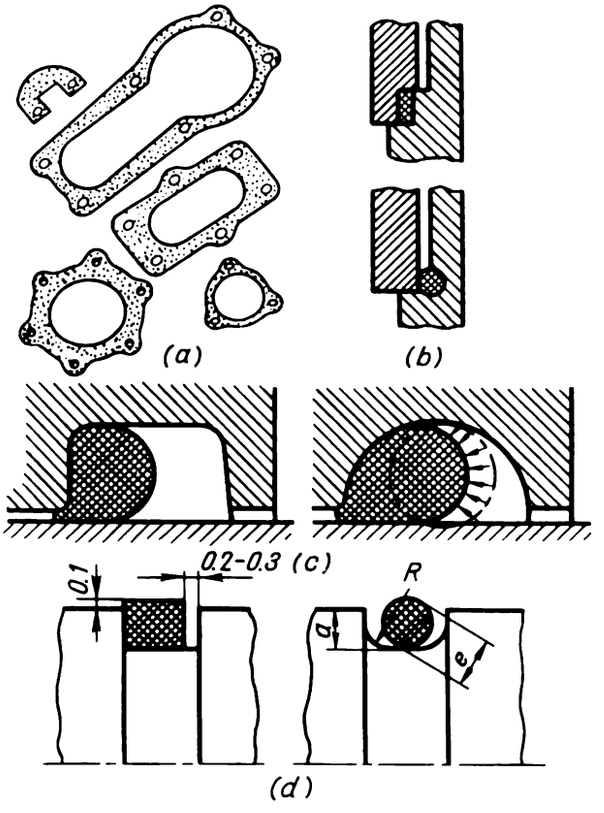


Fig. 528

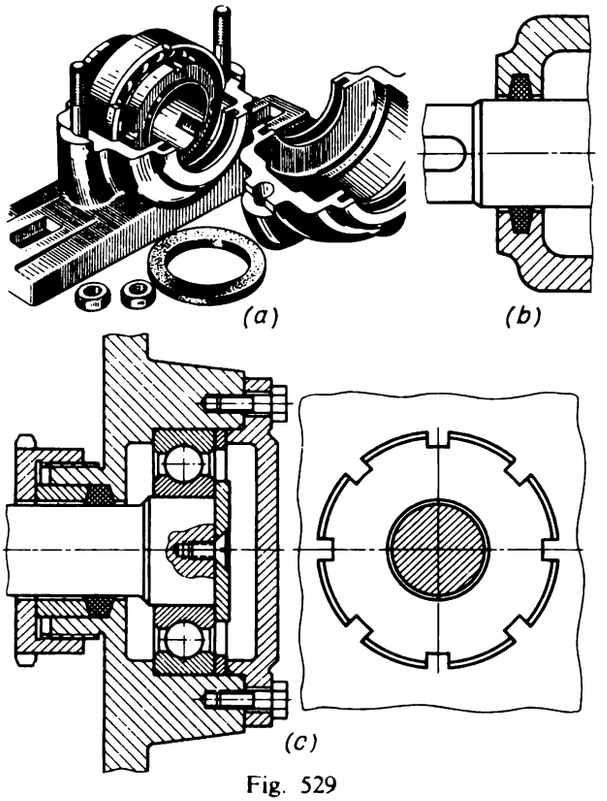


Fig. 529

Depending on the medium under pressure and the operating conditions of the device, gaskets may be made of suitable materials (textolite, sheet rubber, pressboard, paronite, asbestos, cardboard, etc.).

Joints between cylindrical surfaces are sealed by radial packing. In the simplest case, packing rings inserted in annular grooves made in one of the components can be used (Fig. 528*c* and *d*). The size of the rings is selected so that they project from their grooves, thereby sealing off the clearance. Packing rings may have cross sections of various shapes and may be made of various materials (industrial rubber, fabric-base plastics, industrial felt, graphitized asbestos cord, etc.).

Packing rings of industrial felt are employed to prevent the leakage of lubricant through the clearance between a shaft and the housing (or cover) of the bearing in which it runs (Fig. 529*a* and *b*) A packing ring of a rectangular cross section is inserted into a groove of a trapezoidal section. After installation, the ring is deformed and is held tightly against the shaft surface.

In many cases, annular grooves filled with grease serve as a packing for a shaft. Shown in Fig. 530 is a cover with three grooves in the bore through which the shaft passes. The requir-

ed sealing effect is achieved by filling the grooves with thick grease.

Cup packings of various cross sections are used to seal moving parts. The seal between the piston rod and the cover of a hydraulic cylinder (Fig. 531*a*) may consist of a V-cup packing (Fig. 531*b*). The V-rings are expanded to hold them tightly against the piston rod by an end ring which fits into the V-shaped groove of

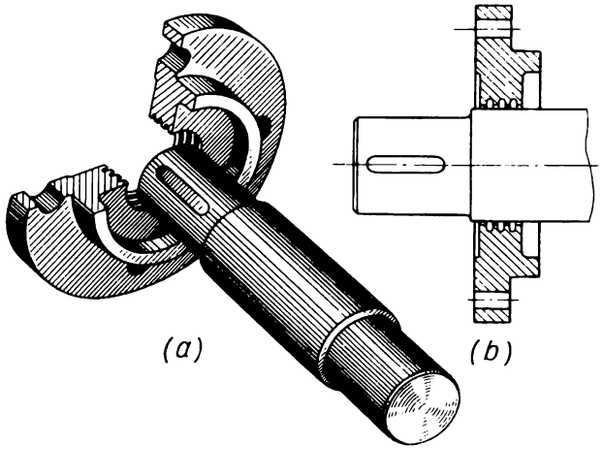


Fig. 530

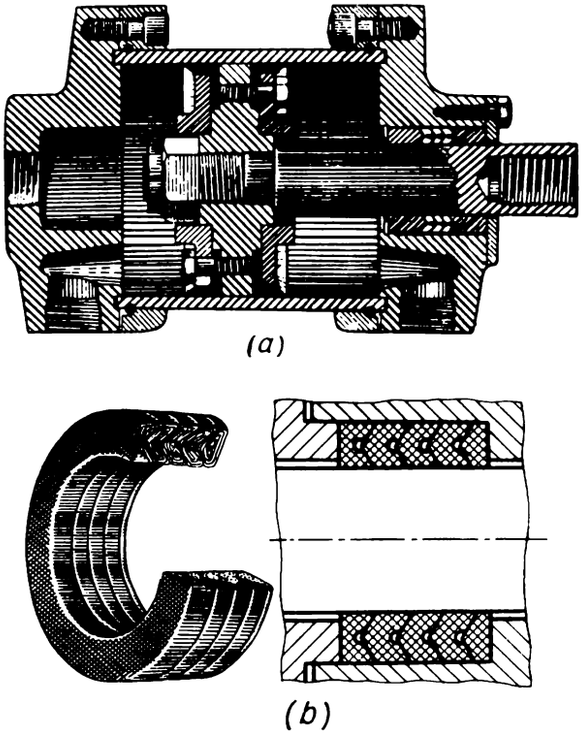


Fig. 531

Table 25

Gland Packings

Working medium	Packing	Cross section
Water, cold and hot	Greased hemp	Square and circular
Superheated water, saturated steam	Greased asbestos	Ditto
Superheated steam	Greased asbestos with graphite and copper wire ("Rational")	Square
Mineral oil	Black greased hemp	Square and circular

the last V-ring. V-rings are made of leather, oil-resistant industrial rubber, leather substitutes (sevanite), capron, PVC, polyethylene and other similar materials.

To seal shafts rotating at high speeds (in reducing gears, engines and other machines) packings and seals of other types are used. These may be of either the enclosed (Fig. 532*a*) or open types (Fig. 532*b*). The most advanced

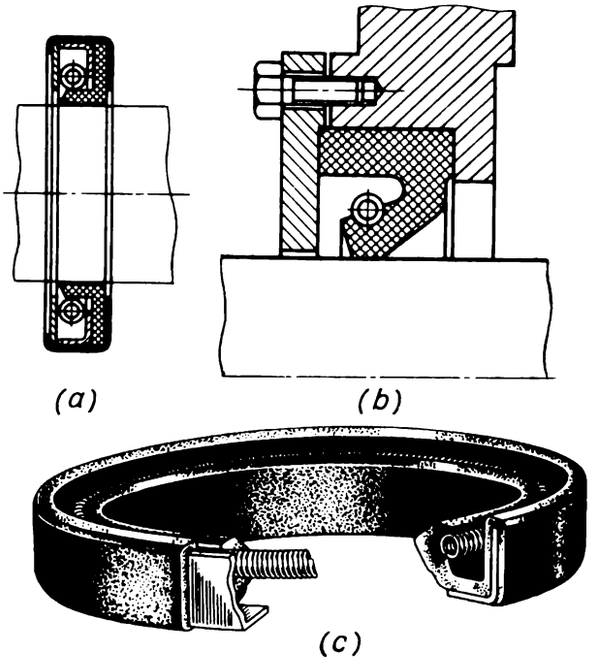


Fig. 532

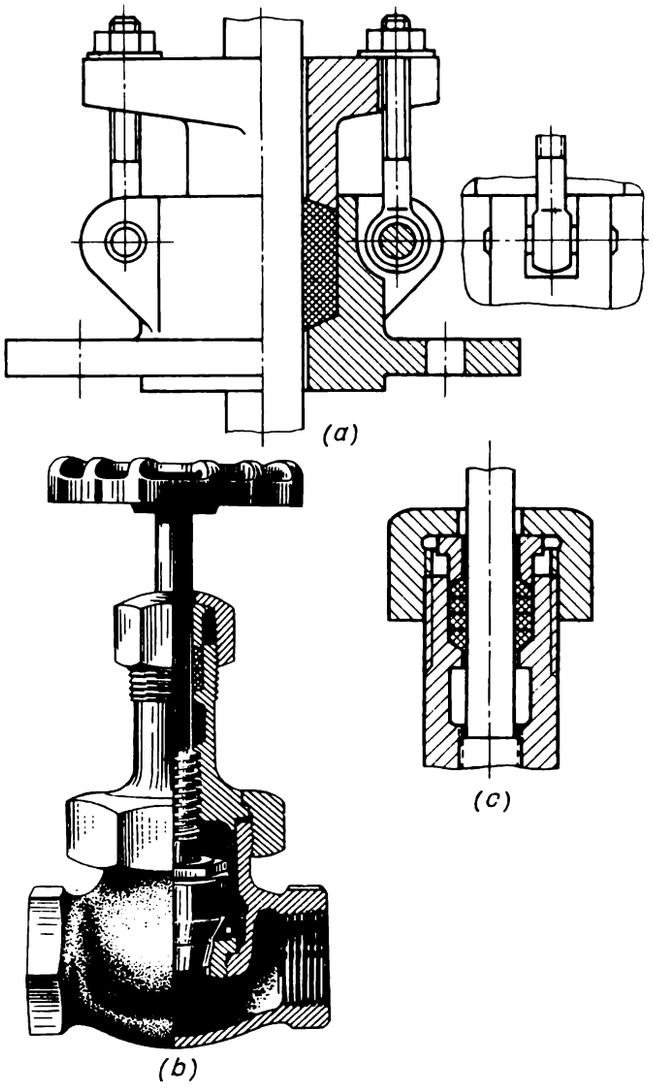


Fig. 533

type is a press-fit enclosed seal (Fig. 532*c*). Here a metal ring is built into a rubber cup. When the cup is free, its inside portion has the shape of a truncated cone, and it is clamped by a metal spring ring which presses the seal against the rotating shaft.

For sealing cylindrical parts of liquid and gas pipe fittings, which move slowly or are only moved from time to time with respect to each other, glands with a soft packing may be used. This packing may be cords of cotton, linen, jute, hemp or asbestos yarn. The cords are impregnated with grease, technical fat or graphite powder. They may be of either round or rectangular cross section (Table 25).

Shown in Fig. 533*a*, *b* and *c* is a packing gland for a globe valve stem. The packing is of a rectangular cross section. When the gland nut is tightened, it presses down on a bushing which compresses the packing. This vertical pressure expands the packing radially so that it fits closely against the valve stem and body. In the drawing of such a packing gland, the bushing is shown in its upper position, contacting the gland nut which is screwed two or three turns on the valve body. This clearly indicates that, as the packing loses its elastic properties, the gland can be regulated by tightening down the nut. A clearance should be shown between the flange of the bushing and the thread of the gland nut. Frequently, the packing in drawings is shown solid (Fig. 533*a*) without indicating the cross section of the cords used in it.

5. DRAWING LUBRICATING DEVICES

The design of most machines and mechanisms incorporates a special, reliable lubricating system.

Insufficient lubrication leads to premature wear, overheating and seizing of the friction surfaces. This may put the machine out of operation.

In making an assembly drawing of a machine that requires lubrication, it is necessary to show the lubricating devices for the friction surfaces and to draw correctly the elements of these devices.

The rubbing surfaces of a shaft journal and a bearing liner can be periodically lubricated with a grease cup of the type shown in Fig. 534*a*. It consists of two parts: a container filled with grease and a lid screwed on the top of the container. The container (or body) of the grease cup is screwed into the bearing cap. The lid is periodically screwed down by hand and some grease is squeezed out. It passes through a hole in the bearing liner and is distributed over the friction surfaces by means of lengthwise or helical lubricating grooves.

The dimensions of grease cups are stipulated by the pertinent standard. Also standard are grease fittings with a ball-type non-return valve (Fig. 534*b* and *c*). Such fittings are filled with a grease gun (Fig. 534*d*). The grease under pressure forces back the ball of the fitting and enters the lubricating system. When enough grease has been fed through the fitting, the gun is removed and the spring lifts the ball. This closes the fitting, keeping the grease inside.

The body of such a grease fitting may be threaded (Fig. 534*c*), or have a smooth cylindrical surface for press-fitting into a reamed hole (Fig. 534*b*).

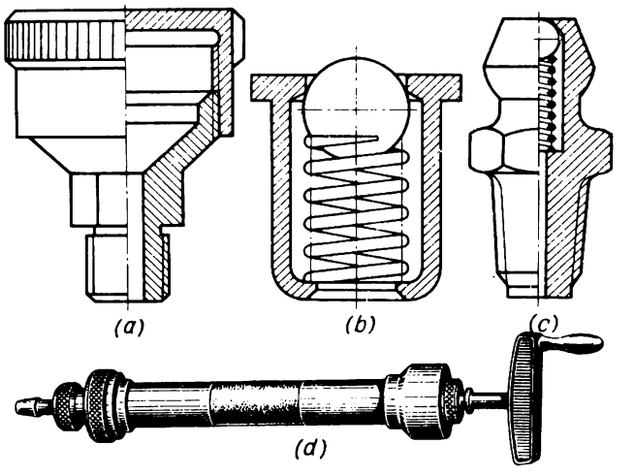


Fig. 534

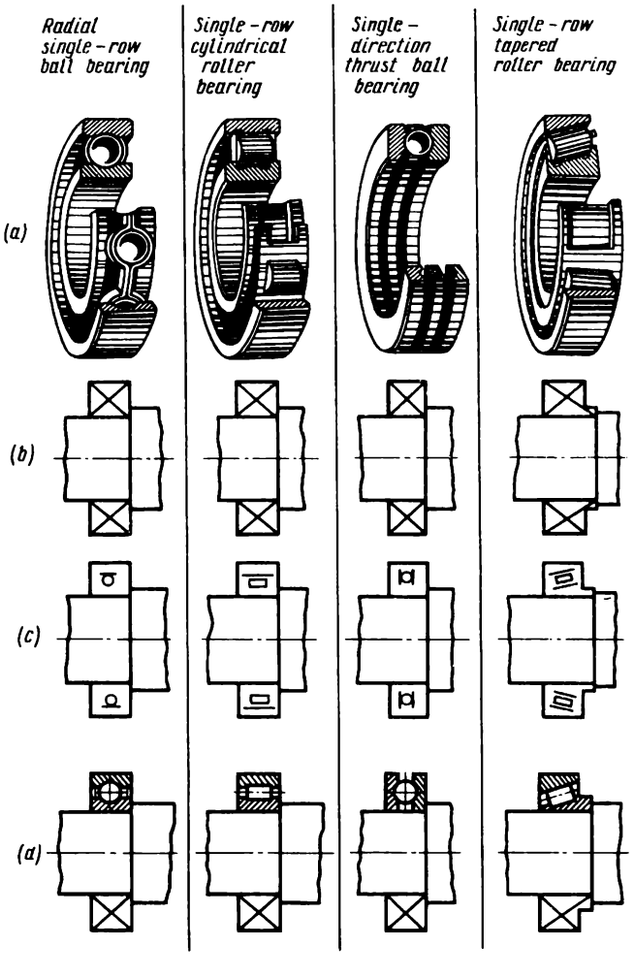


Fig. 535

6. DRAWING BALL AND ROLLER BEARINGS

Ball and roller bearings, manufactured to standards, are widely employed in modern engineering. The most extensively used types of bearings are illustrated in Fig. 535.

Such antifriction bearings consist of the following components: inner and outer races, balls or rollers, and cages (or retainers) which separate and guide the balls or rollers.

In assembly drawings, a simplified representation is used, as a rule, in axial sections of antifriction bearings. The outline of the section is made with thick continuous lines and the diagonals within the section, with thin continuous lines (Fig. 535*b*).

If it is necessary to indicate the type of bearing in the assembly drawing, this is done with a conventional representation, as in Fig. 535*c*.

Section views may also be shown, as in Fig. 535*d*. Though the design of the bearing is more clearly shown, this is also a simplified representation since neither the cage nor the chamfers are shown.

7. DRAWING SPRINGS

Springs are commonly compressed or extended during assembly. The amount of deformation is adjusted by various devices, for example, an adjusting screw (Fig. 536*a*). In assembly drawings, the preload of springs should be taken into account. Thus, they are drawn with the pitch of the coils changed as compared with that in the working detail drawings where it is shown in the free state of the spring.

Helical springs are shown coiled right hand.

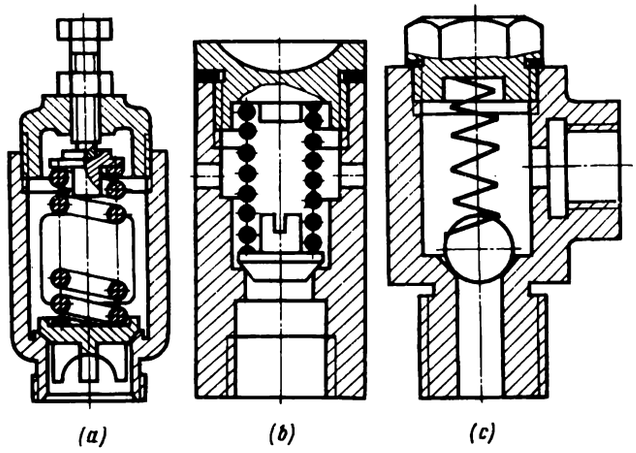


Fig. 536

If there are more than four coils, then one or two coils, in addition to the end coils, are shown at each end. The remaining coils are not shown, but centre lines are drawn through the centres of the wire cross sections over the whole length of the spring. If a spring is in a section view, it is to be drawn as shown in Fig. 536*b*. In cases where the wire cross section does not exceed 2 mm in size, the coil cross sections are blacked in instead of being hatched.

A spring shown in an assembly drawing only by the cross sections of its coils (Fig. 536*b*) is conditionally considered to hide items located behind it up to the outline of the coil cross sections or up to the centre lines of the sections.

If the wire diameter or the thickness of the spring material does not exceed 2 mm in the drawing, the spring can be drawn with straight lines, their thickness being somewhat greater than that of the thick continuous lines used in the drawing (Fig. 536*c*).

8. FEATURES OF ASSEMBLY PROCESSES AND THEIR REPRESENTATION

If a component (bushing in Fig. 537*a* or shaft in Fig. 537*b*) is to be inserted into a mating hole, there should be a chamfer at the front end of the component. A similar chamfer is provided at the end of the hole. These chamfers facilitate assembly.

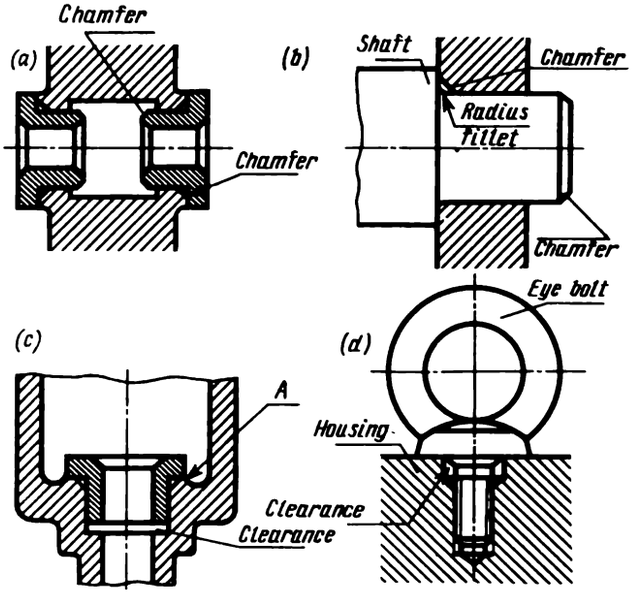


Fig. 537

A fillet is usually provided at a shoulder on a stepped shaft between two steps (Fig. 537*b*). Such a fillet increases the strength of the shaft. If such a fillet is to fit into a hole, the size of the chamfer of the hole should be sufficiently large so that the fillet does not contact the chamfer.

Inside a housing (Fig. 537*c*), the rough (unmachined) surface (usually recognizable by its rounded corners) should be of a larger diameter than that of the press-fitted bushings. This simplifies the machining of the hole into which the bushing is press-fitted.

To avoid misalignment and thus ensure accurate location of two assembled components, one should bear against a single, previously selected locating surface of the other. This is accomplished by providing clearances which exclude the possibility of contact between the other surfaces of the parts (Fig. 537*c*).

The threaded hole in a housing (Fig. 537*d*) is counterbored to a depth greater than the length of the incomplete thread on the eye bolt, to enable the latter to be screwed up to its flange into the housing.

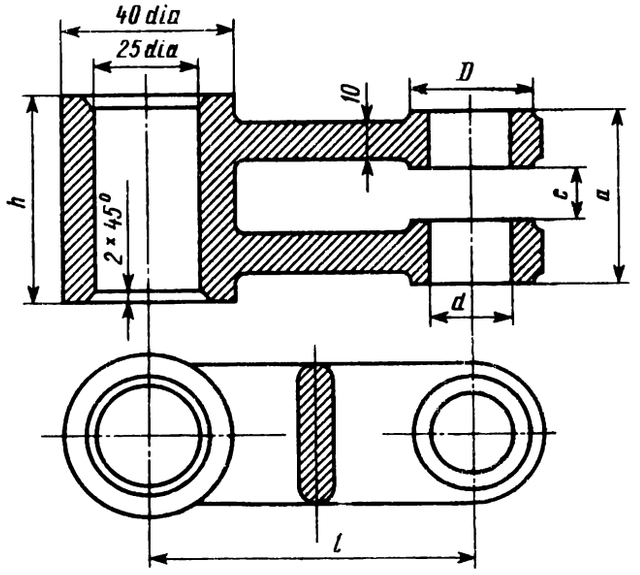
9. TABULAR DRAWINGS

If the product consists of several parts which are similar in shape but have different dimensions, a single tabular drawing can be made for all of these parts instead of a separate drawing for each part. Such a drawing has certain dimensions and a table containing information required to manufacture all the similar components.

An example of a tabular drawing is given in Fig. 538. The drawing contains information necessary for making four levers of similar design, but differing in size. The letters that represent the lever dimensions on the drawing refer, of course, to the dimensions listed in the table.

In a tabular drawing, the title block is filled in the same way as in ordinary drawings. The name of the item (for example, "Lever") is written in the singular. A dash is indicated in the space for the scale of the drawing, and a note "See table", in the spaces for the mass and material (if they differ for the different tabulated items).

It proves expedient in drawing the table to leave some free space at the right and below the table for possible additions.



Modification	Dimensions in mm					
	h	l	D	d	c	a
I	90	140	50	30	20	70
II	100	150	56	34	25	80
III	110	160	62	40	30	90
IV	120	170	70	45	35	100

Fig. 538

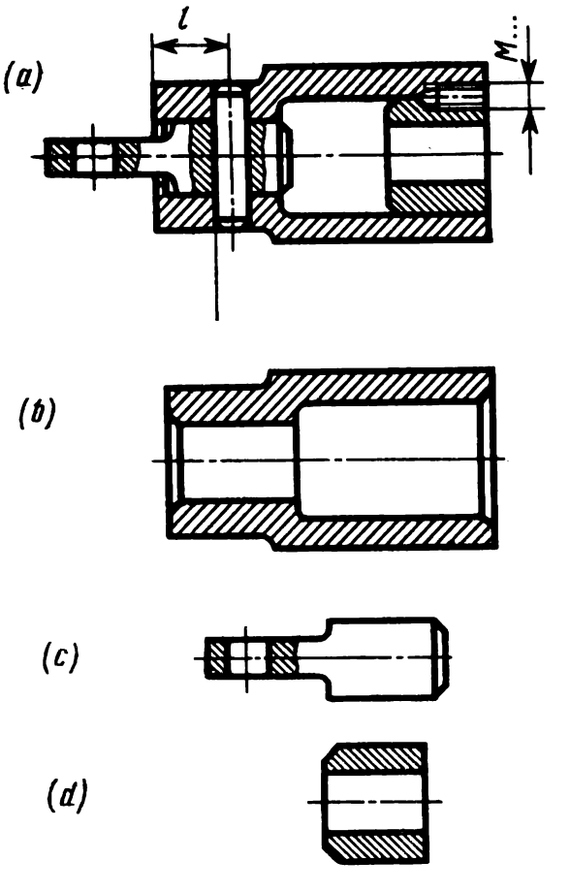


Fig. 539

10. DETAILING PARTS OF AN ASSEMBLY UNIT

The assembly of a product usually consists in joining various parts. These joints may be either separable (bolt, screw and stud joints, and other joints of threaded parts, as well as pin and key joints), or permanent joints obtained by press-fitting, riveting, welding, brazing, soldering, adhesive bonding, hard facing (surfacing), etc.

In a detail (working) drawing, the part should be shown in the condition it is to be delivered for assembly. If any additional machining is required in assembly with other parts (for instance, the drilling of holes for screws and pins), all the data on this machining operation is indicated in the assembly drawing (Fig. 539*a*). Such holes are not shown in the detail drawings of the parts (Fig. 539*b*, *c* and *d*) and no information is given on them in the manufacturing specifications.

Special processing instructions may be specified on assembly drawings if the indicated process or operation is the only one guaranteeing the required guality (Fig. 540).

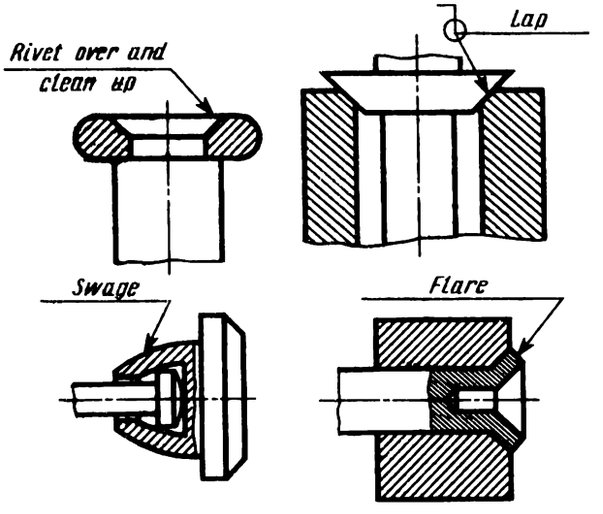


Fig. 540

The extreme and intermediate positions of parts that move in operation may, if necessary, be shown by thin chain (dot-and-dash) lines

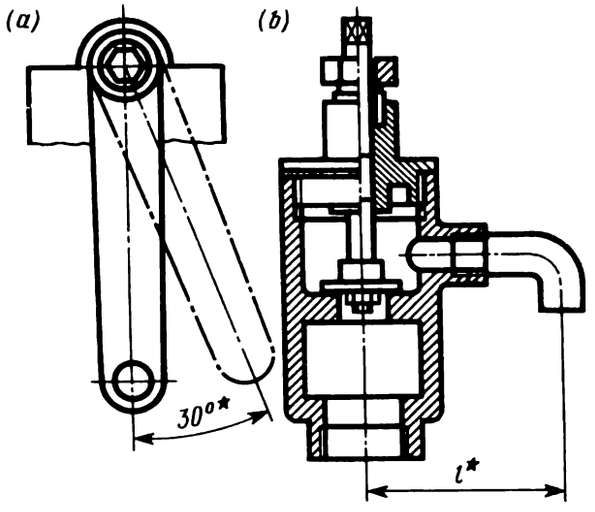


Fig. 541

with the necessary dimensions (Fig. 541*a*). Only the outline of the parts is shown, without any detail.

11. SIMPLIFICATION AND CONVENTIONS FOR ASSEMBLY DRAWINGS

Certain methods of simplifying assembly drawings, as well as certain conventions in addition to those previously indicated, can be applied to save time.

Such methods and conventions have been made use of in the representation of various elements on the assembly drawing of the base of a spring-type shock-absorber (Fig. 542).

On assembly drawings, it is permissible to omit small elements (chamfers, fillets, rounded corners, grooves, projections, depressions, knurling, notches, etc.) and the clearances between the stems of bolts or screws and through holes (Fig. 542*b*, *c* and *d*). Incomplete threads or the uncut portion on a threaded part, or the conical bottom of a blind hole need not be shown (Fig. 542*d*).

Welded, brazed, soldered, glued and other similarly joined items of the same material are hatched, when shown in assembly, as if they were a single piece (hatched in a single direction). The boundary between the component items is shown, however, with a heavy continuous line (Fig. 542*a*).

The transition lines between surfaces can be simplified: special curves can be replaced by circular arcs or straight lines.

If an assembly drawing contains a number of uniformly arranged elements, identical in shape, size, and content (holes, bolts, studs, etc.), it is permissible to show a single element only, the remaining ones being shown either in a simplified manner (conventionally) or not at all, but with their location indicated by centre lines.

Certain assembly units of a product, to be made to individual assembly drawings, may be shown intact in the sectional views of the product assembly drawing. Standard items, such as a grease cup, may be shown in the same way. It is sufficient to show only their outline without any details (projections, grooves, etc.).

If it is necessary to show some component parts of an item, which are obstructed by some other part (cover, shield, hood, etc.), the obstructing part may be omitted, a note, such as: "Cover, No. 4, not shown" or "Cover, No. 4, removed", being made on the assembly drawing.

Items made of a transparent material are usually shown as being opaque. In some cases, components or their elements located behind a transparent item may be drawn as being visible. Examples are scales, dials, hands of instruments, etc.

In sectional views, a portion of the representation may be shown unsectioned, as in Fig. 541*b*.

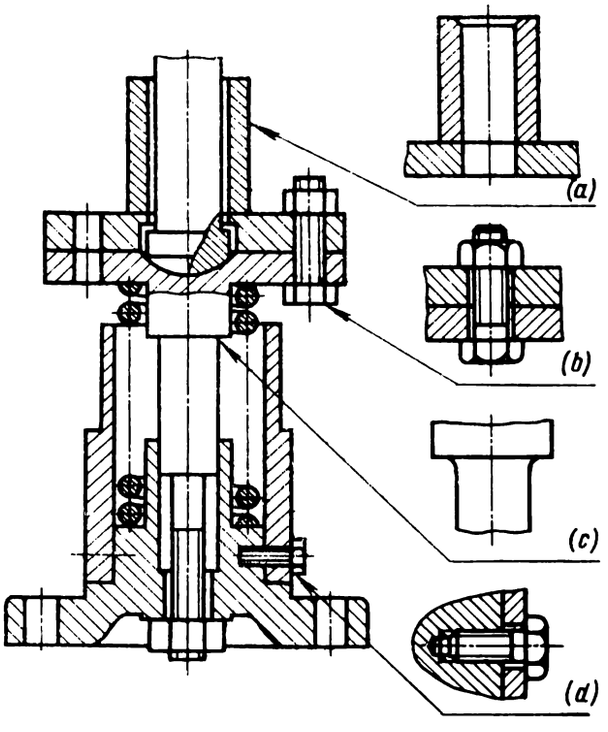


Fig. 542

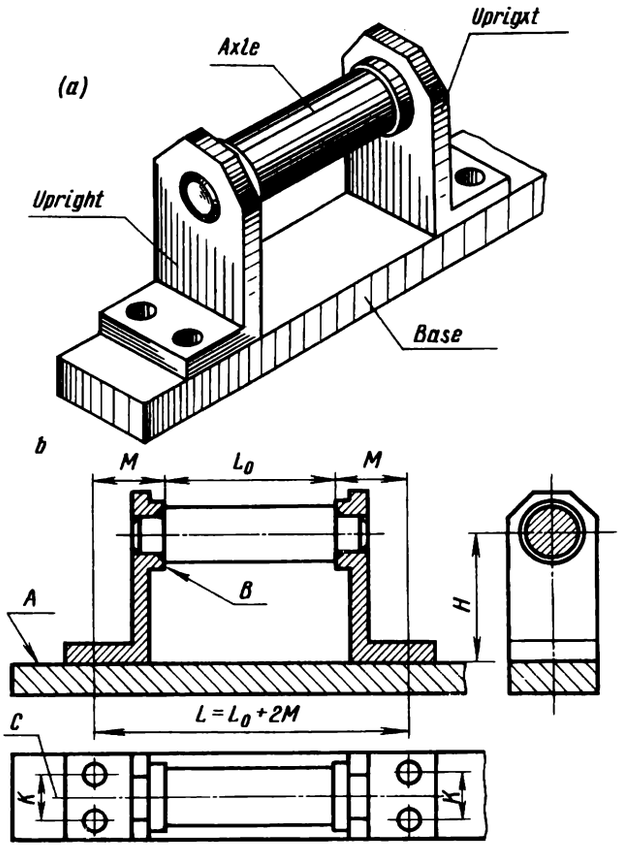


Fig. 543

It is conventionally permissible to shown adjacent (neighboring) items or their elements by thin continuous lines and to give dimensions indicating the mutual positions of the adjacent items (for instance, dimension *l* in Fig. 541*b*).

12. DIMENSIONING ASSEMBLY DRAWINGS

As mentioned in Chapter 4, each part of an assembly unit has surfaces which determine the positions of the mating parts in the same assembly unit. These surfaces are called the design datum surfaces. Such datum surfaces may also be ones which do not actually exist as surfaces on the part, for instance, the plane of symmetry. These surfaces are called latent datum features.

To prevent the axle (Fig. 543) from jamming and seizing as a result of its misalignment with respect to the bracket, it is necessary to obtain the dimensions specified in Fig. 543. Here, the position of the axle is determined by the design datum surfaces *A* and *B*, and the latent datum feature *C* (Fig. 543*b*).

All the dimensions of the bracket (Fig. 544), that determine the shape and position of its elements, are given from the design datum surfaces, taking Fig. 543*a* into account.

If the dimensions of the bracket are not speci-

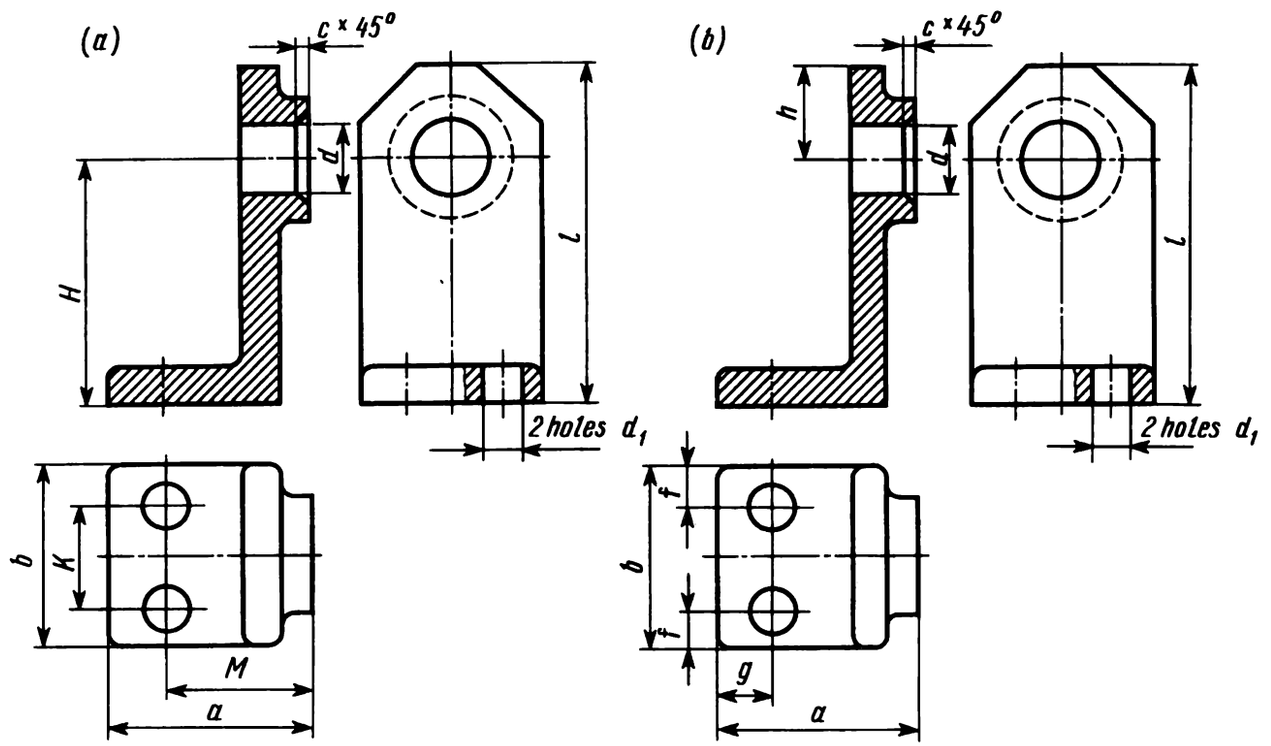


Fig. 544

fied from the design datum surfaces (Fig. 544*b*), the brackets manufactured to such a drawing might not ensure the required position of the axle in the assembly unit (Fig. 543).

It is evident then that the dimensions determining the position of the mating surfaces should, as a rule, be specified from design datum surfaces, taking into account the feasibility of obtaining these dimensions in machining operations and of checking them in inspection.

13. LIMITS OF SIZE (FITS AND TOLERANCES)

In dimensioning a detail drawing, the designer first writes down the *basic sizes* with respect to which the permissible limits of size are determined and permissible deviations applied. The basic size is the common dimension of mating shafts and holes or other mating parts (Fig. 545). Basic sizes are assigned by designers in accordance with standards covering preferred basic sizes, linear dimensions, tapers and angular dimensions.

The *actual size* is that obtained in measuring the finished part.

It is impossible to manufacture absolutely exact parts of machines, i.e., to obtain exact basic sizes. There are various reasons for this, such as wear of the components of machine tools, wear of the cutting edges of tools, deformation of the part during machining, errors in measuring tools, variations in the temperature of the ambient air, etc.

Consequently, the actual sizes of the finished part will always differ from its basic sizes.

In up-to-date large-lot and mass production, when a large number of identical parts are to be manufactured, it is necessary that their actual sizes should lie within definite limits which:

(1) enable the mating parts to be assembled without any additional fitting operations;

(2) ensure the required operating properties, reliability and service life of the articles assembled from the manufactured parts.

Parts meeting these requirements are said to be *interchangeable*, and the production of such parts is called interchangeable assembly manufacturing.

The two permissible limiting sizes between which (or equal to which) the actual size may be are called the *limits* of *size* (Fig. 545). The larger is called the *maximum* and the smaller, the *minimum limit of size*. A limiting deviation of size is the algebraic difference between a limit of size and the basic size. Distinction is made between the *upper* and *lower limiting deviations*. The upper limiting deviation is the algebraic difference between the maximum limit of size and the basic size. The lower limiting deviation is the algebraic difference between the minimum limit of size and the basic size (Fig. 545). The limiting deviation may be either positive (denoted by a plus sign), if the limit of size is greater than the basic size, or negative (denoted by a minus sign), if it is less than the basic size.

With a positive limiting deviation, the actual size may be greater than the basic size; with a negative limiting deviation it may be less.

The upper and lower limiting deviations may be equal or may differ in magnitude. One of the deviations may be zero.

The difference between the maximum and minimum limits of size or, more exactly, the *magnitude of the algebraic difference between the upper and lower limiting deviations* is called the *tolerance*, and the *zone* between the limits of size is called the *tolerance zone* (Fig. 545).

The position of the tolerance zone and its

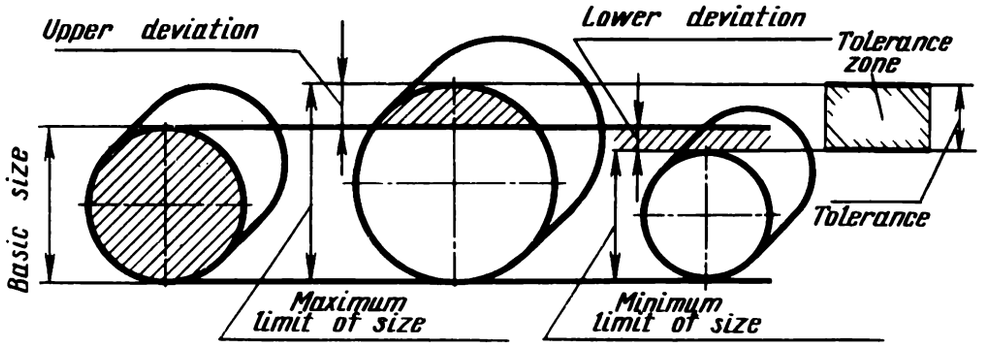


Fig. 545

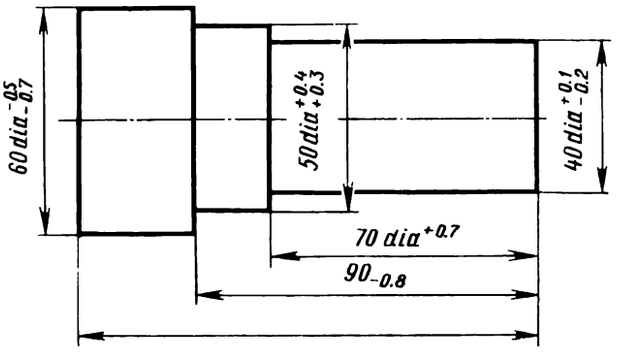


Fig. 546

extent are determined by: (1) the magnitude of the tolerance, and (2) the location of the tolerance with respect to the basic size. In a graphic representation, the tolerance zone is the interval of sizes between two straight lines corresponding to the upper and lower permissible deviations with respect to the so-called *zero line*.

The zero line corresponds to the basic size from which the deviations of size are laid off in the graphical representation of tolerances. When the zero line is horizontal, positive deviations are laid off upward, and negative deviations downward.

Drawings are toleranced by specifying the basic size and the permissible limiting deviations in size which are determined by the required accuracy in machining the part (Fig. 546). According to the pertinent drawing standard, the limiting deviations with their signs (+ or −) are specified directly following the basic size (Fig. 546). The upper limiting deviation is to be placed above the lower one. Limiting deviations equal to zero are omitted. The height of the figures indicating the deviations should be less than that of the figures specifying the basic size. If the upper and lower limiting deviations are equal in magnitude, then this value is specified once, with figures of the same size as those specifying the basic size, preceded by the ± sign.

From the limiting deviations of the basic sizes specified in Fig. 546, the limits of size, tolerances and tolerance zones can be determined by calculations.

In any joint of two mating components, where one component *envelopes* the other (Fig. 547), distinction is made between the *enveloping* and the *enveloped* surfaces. The enveloping surface is conventionally called the *hole*, and the enveloped surface, the *shaft*.

These surfaces may be of various shapes, for instance, surfaces of revolution (Fig. 547*a*) flat surfaces (Fig. 547*b*), etc.

If size D_1 of the hole is greater than size d_1 of the shaft (Fig. 548*a*), a *clearance*, $\delta_1 = D_1 - d_1$, results when the mating components are assembled. This clearance allows the mating components to move freely relative to each other.

If before assembly the size d_2 of the shaft is greater than the size D_2 of the hole (Fig. 548*b*), an *interference*, $\delta_2 = d_2 - D_2$, results when the mating components are joined. The amount of interference determines the resistance to motion of one component with respect to the other. The greater the interference, the higher the resistance.

The joint obtained between mating parts, determined by the difference between their sizes

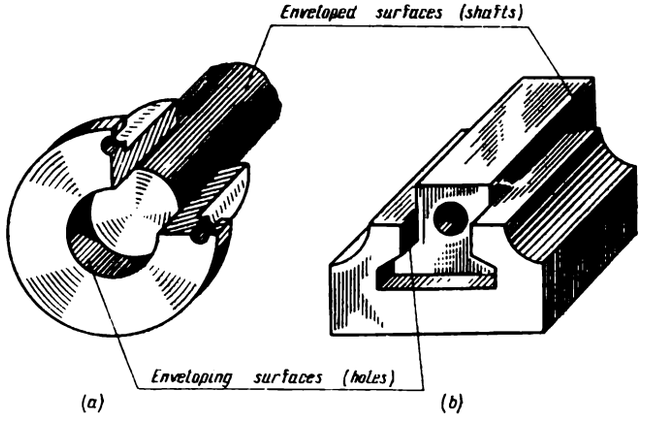


Fig. 547

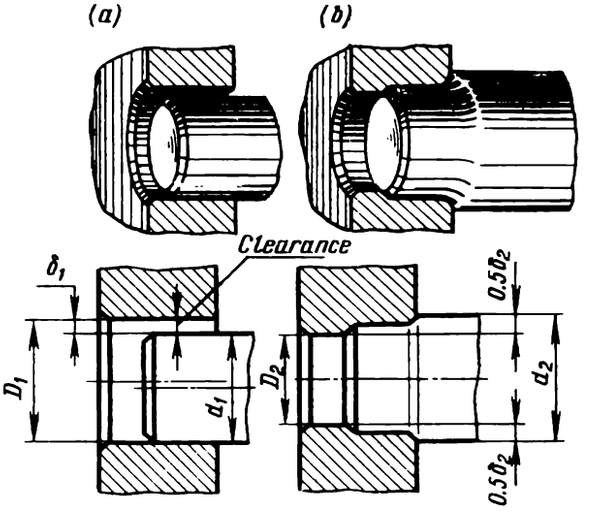


Fig. 548

before assembly, i.e., by the amount of clearance or interference, is called the *fit*.

There are a great number of fits which can be classified into three general types:

(1) interference fits (with guaranteed interference) which form fixed joints excluding relative motion between the mating components;

(2) transition fits, i.e., fits in which there may be either interference or clearance (depending upon the actual sizes of the mating components), which are used for fixed joints only in conjunction with an additional fastener, such as a key, pin or screw;

(3) clearance fits (with guaranteed clearance) which form movable joints between the mating components.

A new system of fits and tolerances has been developed by the member countries of the CMEA (Council of Mutual Economic Aid), consisting of Bulgaria, Cuba, Czechoslovakia, the GDR, Hungary, Mongolia, Poland, Romania, and the USSR, in accordance with that adopted by the ISO (International Organization of Standardization).

Here, the deviations of size are denoted by the following conventional symbols: *ES* and *EI* are the upper and lower deviations of the hole, and *es* and *ei* are the upper and lower deviations of the shaft.

The fits for each basic size have a whole series of tolerances and basic deviations which specify the position of these tolerances with respect to the zero line.

The tolerance depends upon the basic size and the grade of accuracy which is specified by a number. The standard stipulates nineteen *grades of accuracy*, identified by the numbers (in the order of decreasing accuracy) 01, 0, 1, 2, 3, ..., and 17.

The position of the tolerance zone with respect to the zero line is indicated by a letter symbol (or, in one case, by two letters), a capital letter for holes and a small letter for shafts, for example, 40g6, 40H7, 40H11, etc.

The tolerance system provides for the following fundamental deviations (for the basic size range from 1 to 500 mm), arranged in the order of increasing shaft size and decreasing hole size (i.e., in the order of decreasing clearance and increasing interference):

a b c d e f g js k m n p r s t u x z

A B C D E F G Js K M N P R S T U X Z

Thus, as indicated above, a tolerance size is specified on a drawing by a number equal to the basic size, followed by a letter (or letters) indicating the position of the tolerance zone, and a number indicating the grade of accuracy (50g6, 50H7, etc.).

A fit is specified by the basic size common to both components (hole and shaft), followed by symbols referring to each component, the hole coming first, for instance: 40H7/g6 or 40H7-g6 or $40\frac{H7}{g6}$.

Two systems of fits are employed: the *basic-hole system* and the *basic-shaft system*. In these systems, the various fits are obtained by assigning the tolerance zone of only one of the mating parts, while the tolerance zone of the other part is constant for all the fits of the same basic size and grade of accuracy. This reduces the number of tools required to manufacture and check the parts (reamers, broaches, gauges, etc.).

In the basic-hole system, the lower limiting deviation of the hole equals zero for all fits, while the upper deviation is constant for all fits of the same grade of accuracy and depends on the basic size of the hole. The various fits are obtained by changing the limiting deviations of the shaft.

In the basic-shaft system, the upper limiting deviation of the shaft equals zero for all fits, while the lower deviation is constant for all fits of the same grade of accuracy and depends upon the basic size of the shaft. Here the various kinds of fits are obtained by varying the limiting deviations of the hole.

The basic-hole system is more widely employed in engineering, because this reduces the number of tools required to make holes which can be used in any fits. Hole-making tools are much more expensive than those required to make shafts.

The basic-shaft systems finds application to enable a plain shaft to be used instead of a stepped one to obtain different fits at different portions of the shaft, at which various components are mounted. It is also used in seating the outer races of ball and roller bearings in housing bores.

The tolerances of linear dimensions can be specified on drawings by one of three methods:

1. By indicating the tolerance zone symbol, for example, 18H7 or 12e8.

2. By indicating the numerical values of the

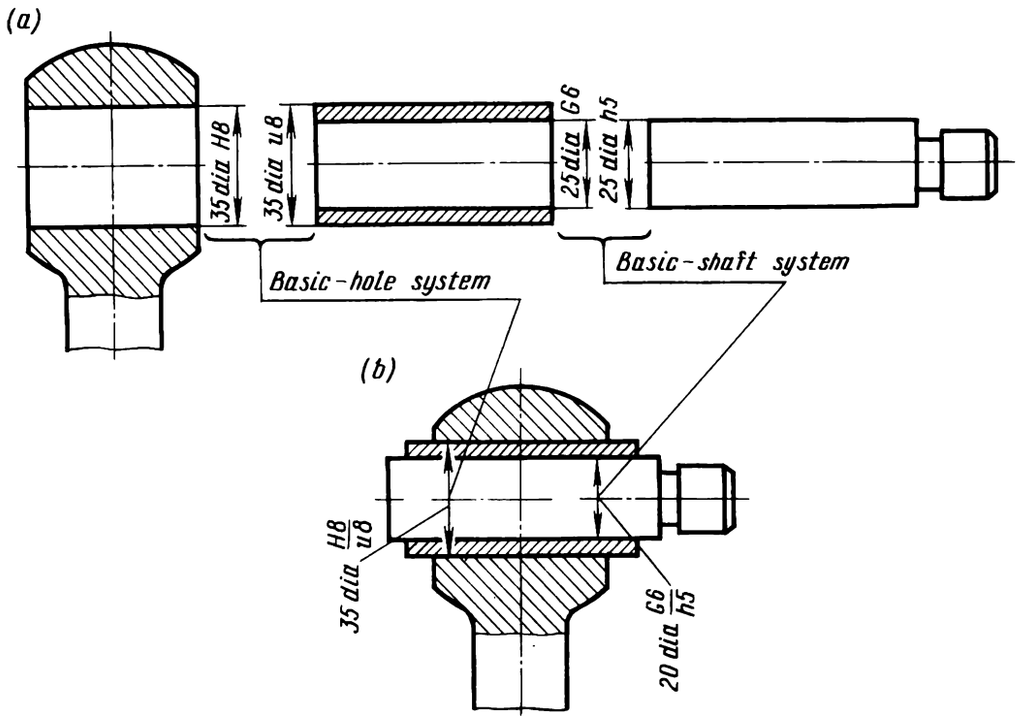


Fig. 549

limiting deviations, for example, $18^{+0.018}$ or $12^{-0.032}_{-0.059}$.

3. By indicating the tolerance zone symbol followed by the numerical values of the limiting deviations enclosed in parentheses, for example, $18H7^{(+0.018)}$ or $12e8(^{-0.032}_{-0.059})$. The 2nd and 3rd methods are recommended.

Items in the manufacturing specifications on a drawing may give information on coarse tolerances required (from grade 12 and coarser) when the limiting deviations are not indicated in any way following the dimensions. Such items may be worded as follows:

"*Except where otherwise stated, hole tolerances are to be H14, shaft tolerances, h14.*" In this example, H14 refers to the dimensions of all external elements (enveloping elements of joints) and h14 to all internal elements (enveloped).

Examples of the specification of tolerances to obtain a force fit in the basic-hole system with accuracy grade 8, and a sliding fit in the basic-shaft system with accuracy grades 5 and 6 are given in Fig. 549.

The tolerances of angular dimensions are determined according to the pertinent standard and are indicated on drawings by numerical values.

It should be noted that in special cases in the manufacture and fitting of mating parts, for example, ball and roller bearings, spline fittings, parts and articles of plastics or wood, key joints, etc., the pertinent standards cover the required grades of accuracy, limiting deviations or tolerances and fits (as well as the conventional symbols used to specify them).

All the above information on fits and tolerances, their designation on drawings, etc. are only given to enable the student to become acquainted with production drawings. Tolerances, fits and other permissible deviations of dimensions are not usually indicated on training drawings.

14. GEOMETRICAL TOLERANCES

The shape of any surface, as well as the relative location of the surfaces of a manufactured part, deviate in practically all cases from what was indicated on the drawing in designing the part. Geometrical tolerances, i.e., tolerances as to the shape and location of surfaces, are covered by the pertinent standards. These tolerances are specified by means of special symbols or in the text of the manufacturing specifications on the drawing.

Table 26

Symbols Specifying the Shape of Surfaces
(Geometrical Tolerances)

Type of error		Symbol
Briefly	Interpretation	
Flatness	Deviation from a flat surface	▱
Straightness	Deviation from a straight line	—
Cylindricality	Deviation from a true cylinder	⌭
Roundness	Deviation from a true circle	○
—	Deviation of profile in a longitudinal section (refers to cylindrical surfaces)	⌓

Symbols used for specifying the shape of surfaces are listed in Table 26. Those specifying the relative location of surfaces are listed in Table 27.

Data about the tolerances on the shape and location of surfaces are conventionally indicated on drawings in a rectangular box divided into two or three parts (Fig. 550*a*). Placed into the parts of the rectangular box are the following data: the geometrical tolerance symbol in the first part (according to Table 26 or 27), the value

Table 27

Symbols Specifying the Relative Location of Surfaces
(Geometrical Tolerances)

Type of error		Symbol
Briefly	Interpretation	
Parallelism	Lack of parallelism	//
Squareness	Lack of squareness	⊥
Coaxiality	Lack of coaxiality	⌖
—	Face, or axial, runout (wobble)	↓
—	Radial runout	
Intersection of axes	Lack of correct intersection of axes	×
Symmetry	Lack of symmetry	÷
—	Deviation of axes from nominal position	⌖

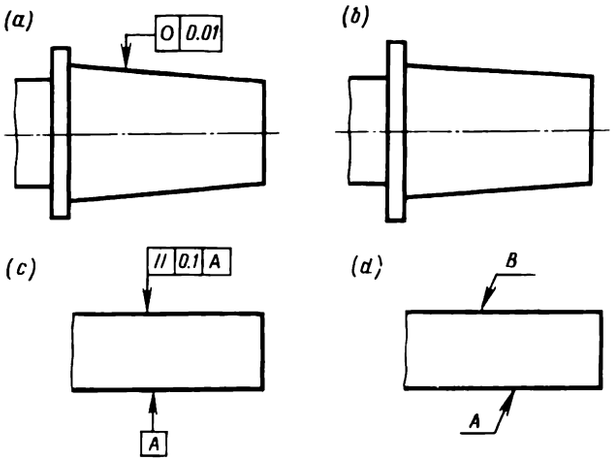


Fig. 550

of the tolerance in mm in the second, and, in the third part, the letter indicating the surface with respect to which the relative location of the given surface is specified (on the drawing, a leader with this letter indicates the corresponding surface).

The rectangular boxes are drawn with thin continuous lines. The height of the figures, letters and symbols shown in the box should equal the height of the dimensional figures.

An example of a geometrical tolerance, or tolerance of shape (in the given case, the out-of-roundness of a taper), is given in Fig. 550*a*. If the manufacturing specifications list the requirement: "*Out-of-roundness of taper within 0.01 mm*", the drawing is made as shown in Fig. 550*b*. Another wording may be "*Taper round within 0.01 mm*".

Shown in Fig. 550*c* is the conventional designation for the tolerance on the parallelism of two flat surfaces. The drawing may be as shown in Fig. 550*d* if the manufacturing specifications include the requirement: "*Lack of parallelism of surfaces A and B within 0.1 mm*" or "*Surface B parallel to A within 0.1 mm*".

15. MAKING A TRAINING ASSEMBLY DRAWING OF A FINISHED ARTICLE

A common assignment in a drawing course is to make an assembly drawing of a finished article. The order of procedure is:

(a) becoming acquainted with the article;

(b) distributing the components of the article among the sections of the parts list and assigning designations to them;

(c) sketching all the parts that are to be made in manufacturing the article; parts which belong to "standard items" or "other items" are not usually sketched;

(d) making the parts lists and assembly drawings of the assembly units which are part of the article;

(e) making the parts list and assembly drawing of the article.

(a) *Becoming Acquainted with the Article*

Before making an assembly drawing of an article (or its component parts), it is necessary to become acquainted with the purpose, design, interaction and material of the component parts of the article.

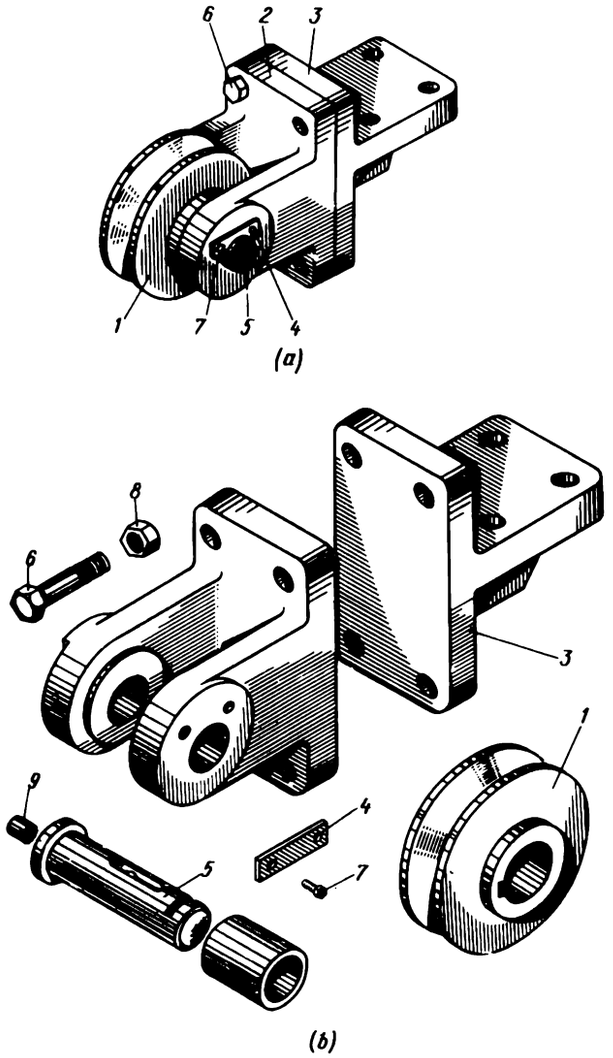


Fig. 551

This can be made considerably easier if the student has the opportunity to read some of the engineering documents that specify or describe the article in some way (Machine Certificate, Service Manual, Manufacturing Specifications, Explanatory Notes, etc.).

Let us consider an assignment for making an assembly drawing of a "Guide Pulley" (Fig. 551*a*). This assembly unit is to be mounted on the steel structure of a crane and serves for guiding a wire rope.

The wire rope enters the groove of pulley *1* (Fig. 551*a*) and runs over the pulley with a certain definite angle of contact. Pulley *1* turns freely on axle *5* which is fixed in the lugs of bracket *2* by locking strip *4* which fits into a slot in axle *5*. Strip *4* is secured to bracket *2* by two screws *7*.

Grease is delivered from ball-type grease fitting *9* along cylindrical grooves in axle *5* to reduce friction when the pulley rotates.

Bracket *2* is attached by four bolts *6* with nuts *8* to bracket *3* which, in its turn, is secured by four bolts to the steel structure of the crane.

Before making any drawings it is necessary for the student to disassemble the pulley himself, determine the geometrical shapes of the components, find out what kind of joints hold the components together and establish the sequence of assembly operations (Fig. 551*b*).

(b) *Distributing the Components Among the Sections of the Parts List and Assigning Designations*

Shown in Fig. 551*b* are the component parts of the "Guide Block", which can be distributed among the sections of the parts list as follows:

1. The "Pulley" is an *assembly unit* consisting of the pulley proper into which a sleeve is press-fitted. Hence, the "Pulley" belongs in the section "Assembly Units". As such, it requires an assembly drawing and a parts list made and drawn up on the basis of sketches of its component parts (pulley proper and sleeve).

2. The component parts: "Bracket", "Bracket", "Locking Strip" and "Axle" belong in the section "Parts". A sketch is to be made of each of these component parts.

3. As component parts, the bolts, nuts and grease fitting belong in the section "Standard Items" and no sketches are required for them.

The designation of the article as a whole is written on the training assembly drawing, and

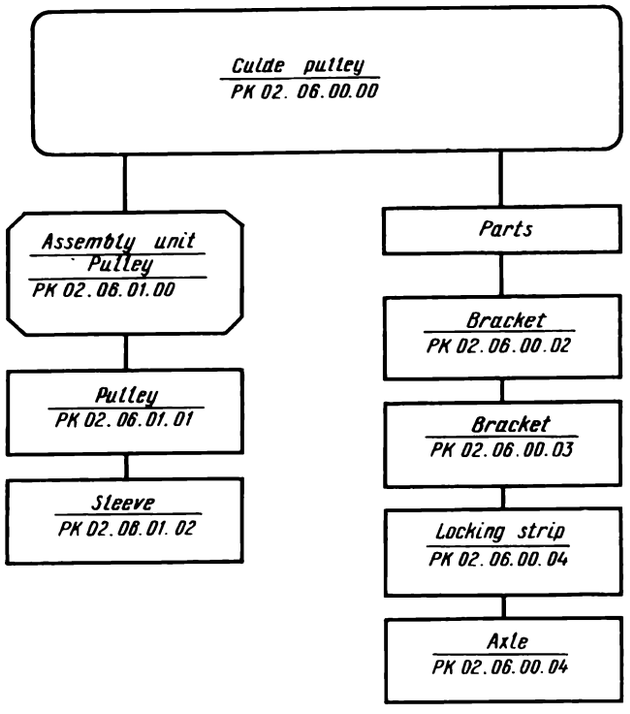


Fig. 552

designations are assigned for all the component parts.

A diagram of the component parts of the "Guide Pulley" is given in Fig. 552. Either drawings or sketches are to be made of these parts. Designations are assigned by analogy with the diagram of Fig. 525.

(c) *Sketching the Component Parts*

Parts are to be sketched in accordance with the recommendations and rules given in Chap. 4. The sketches should be made on sheets of standard sizes. Graph paper is especially convenient for sketching.

The arrangement of the views in the sketch should be such as will ensure convenience in making the parts to the sketches.

Special attention should be paid to the correspondence of the sizes of the mating surfaces. The material selected for each part should meet the requirements for its function (purpose) in the assembly unit.

The *sketches* of the two brackets, parts *2* and *3*, in Fig. 553, should each have three views: main view, top view and left-hand view. These three views should reveal the shapes of all the elements of the parts. Holes in the parts are shown by means of broken-out sections. A view facing arrow *A* is given to reveal the shape of an element of part *2*.

The sketch of locking strip *4* has a frontal section and a top view. Axle *5* can be adequately represented by one main view with a broken-out frontal section and Section *A-A* that shows the shape and location of the lubricating groove (Fig. 554).

Pulley *1* of the guide pulley assembly unit is also an assembly unit and therefore its components, the pulley proper and the sleeve, are sketched (Fig. 555). No sketch is required for set screw *7*, as it is a standard item.

The hole for the set screw is drilled and tapped after assembling the pulley with the sleeve. It is therefore not shown on the sketches of the component parts (Fig. 555). The assembly drawing of the pulley is given in Fig. 556. It is employed to press-fit the sleeve, and to drill and tap the whole for the set screw. A single view of this assembly unit is sufficient; it can be drawn on a sheet of Size 11.

When, as in our case, the assembly drawing is on a Size 11 sheet, the parts list may be put on the same sheet.

(d) *Making the Parts List and Assembly Drawing of the "Guide Block"*

On an assembly drawing, the component parts of an article are assigned component numbers in the same sequence they are indicated in the parts list. Consequently, the parts list must be compiled before indicating the numbers on the assembly drawing.

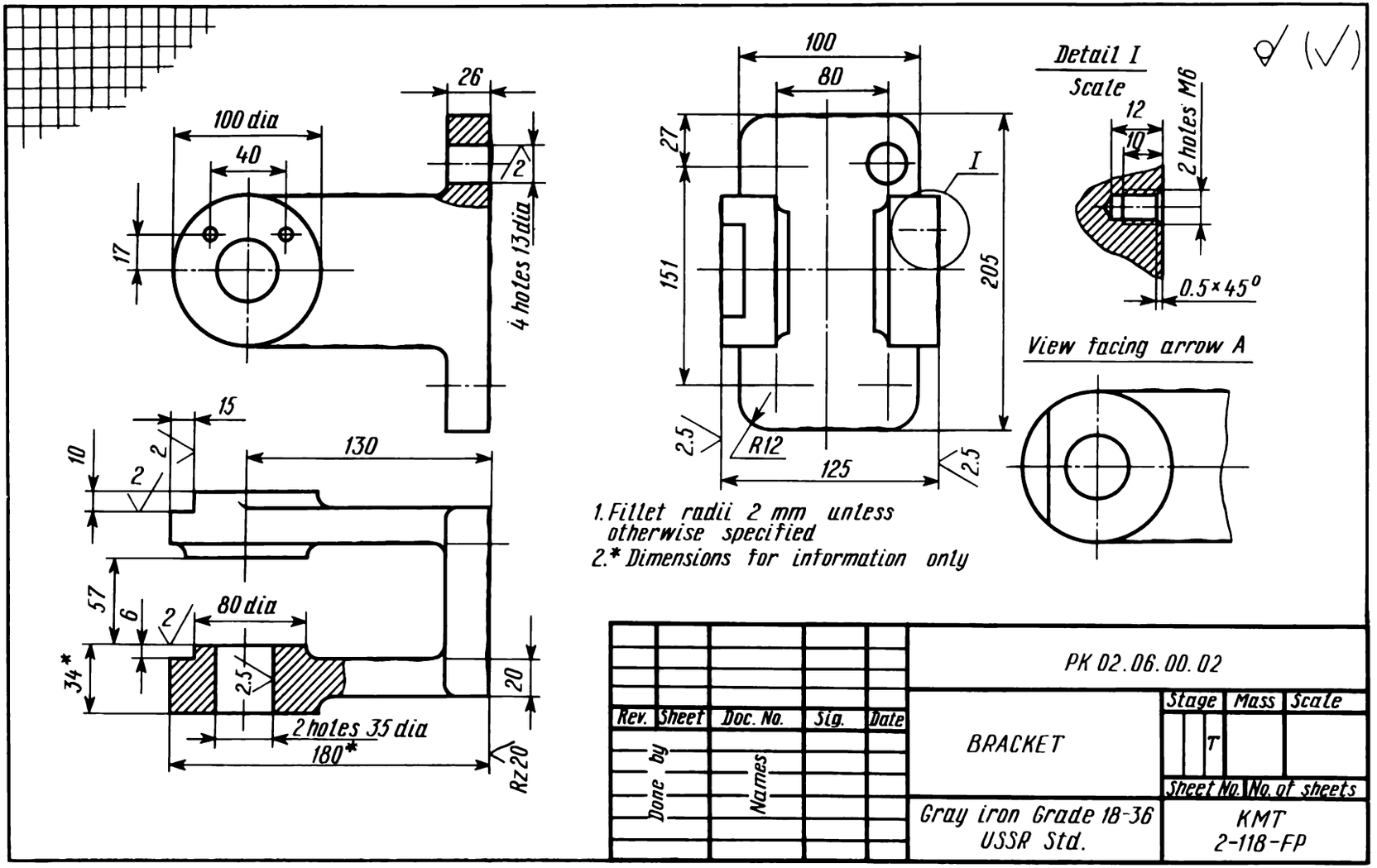
In training practice, the parts list can be located in a free space of the training assembly drawing even if the latter is made on a sheet other than Size 11 (Fig. 557).

In Figure 557 the parts list is compiled in accordance with the rules set forth in Sec. 2, using the designations assigned to the component parts of the article in the diagram in Figs. 525 and 552.

An assembly drawing (Fig. 557) is usually to be made in the following order:

1. Determine the number of views required.
2. Choose a suitable scale for the views.
3. Select a paper sheet of the necessary size.
4. Arrange the views properly on the sheet.
5. Draw the views.
6. Dimension the drawing.
7. Indicate the ordinal numbers of the parts.

There should be as few views as is feasible to


26
100 dia
40
2
17
4 holes 13 dia
15
10
2
2
130
57
6
2
80 dia
34*
2.5
20
2 holes 35 dia
180*
Rz 20
100
80
27
151
205
I
2.5
R12
125
2.5
Detail I
Scale
12
10
2 holes M6
0.5×45°
View facing arrow A
1. Fillet radii 2 mm unless otherwise specified
2.* Dimensions for information only
Rev.
Sheet
Doc. No.
Sig.
Date
Done by
Names
PK 02.06.00.02
BRACKET
Stage
Mass
Scale
T
Sheet No.
No. of sheets
Gray iron Grade 18-36
USSR Std.
KMT
2-118-FP

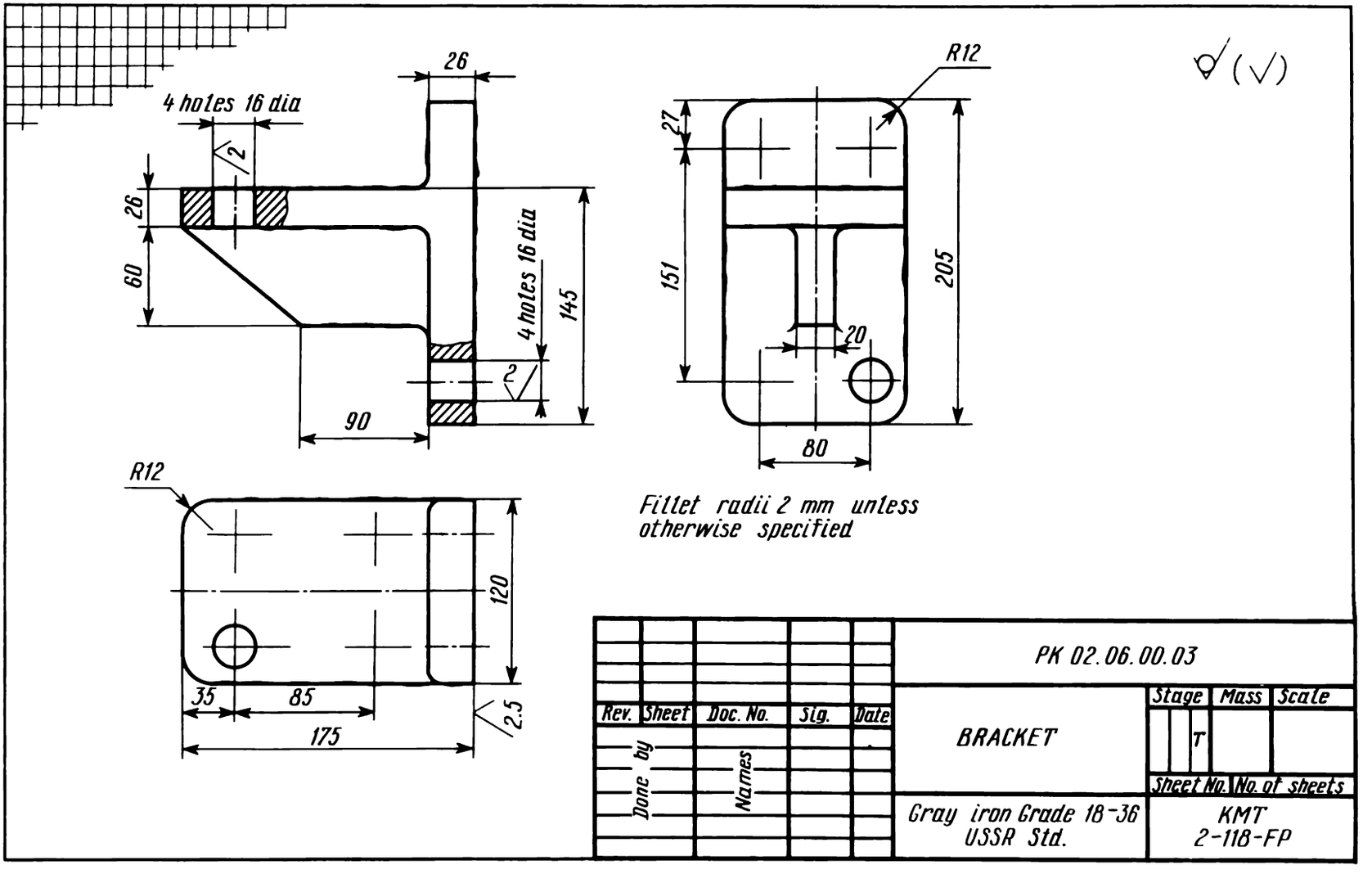
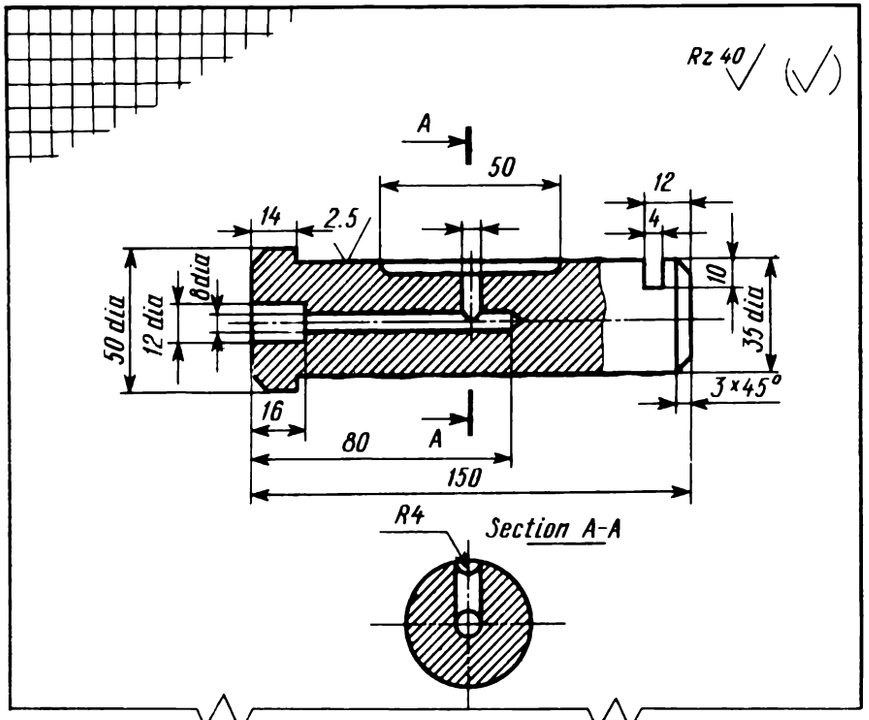
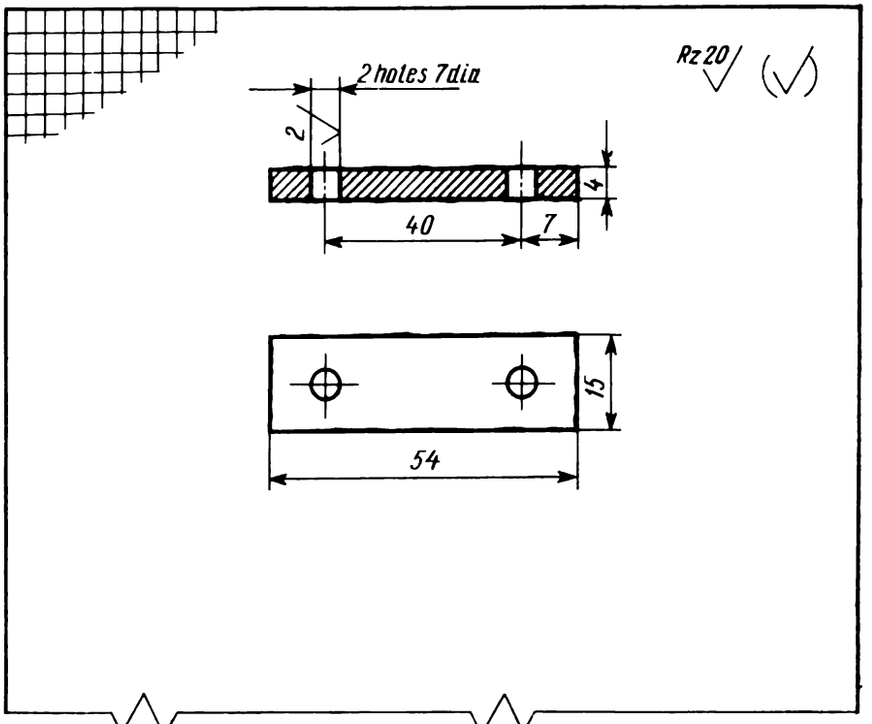

26
4 holes 16 dia
2
26
60
4 holes 16 dia
145
2
90
R12
27
151
205
20
80
R12
120
35
85
175
2.5
√(√)
Fillet radii 2 mm unless otherwise specified
PK 02.06.00.03
Rev.
Sheet
Doc. No.
Sig.
Date
Done by
Names
BRACKET
Stage
Mass
Scale
T
Sheet No.
No. of sheets
Gray iron Grade 18-36
USSR Std.
KMT
2-118-FP

Fig. 553





Rev.	Sheet	Doc. No.	Sig.	Date	PK 02.06.00.05			
Done by / Names					AXLE	Stage: T	Mass	Scale
						Sheet No.	No. of sheets	
					Steel Grade 45 USSR Std.	KMT 2-118-FP		

Rev.	Sheet	Doc. No.	Sig.	Date	PK 02.06.00.04			
Done by / Names					LOCKING STRIP	Stage: T	Mass	Scale
						Sheet No.	No. of sheets	
					Steel Grade 5 USSR Std.	KMT 2-118-FP		

Fig. 554

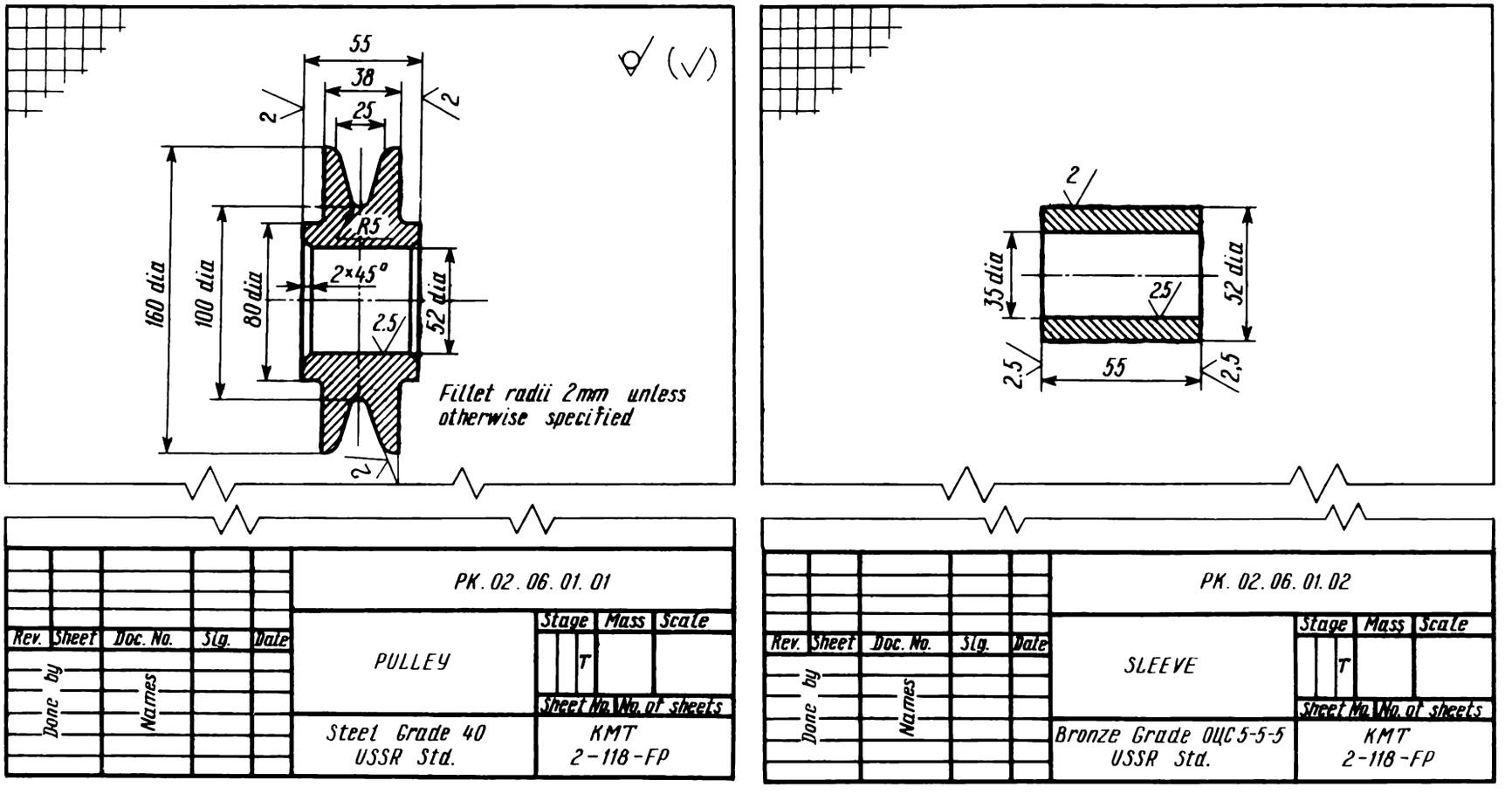
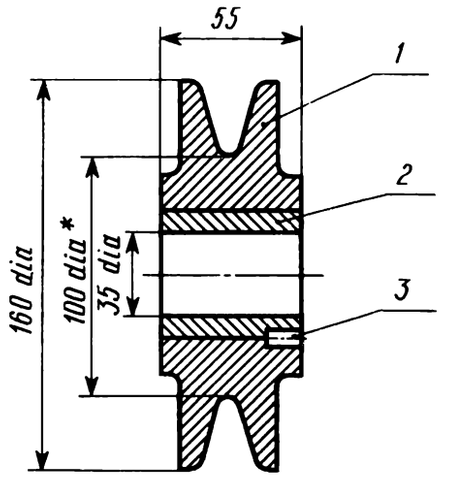

55
38
25
2
2
R5
160 dia
100 dia
80 dia
2×45°
52 dia
2.5
2
Fillet radii 2mm unless otherwise specified
2
35 dia
25
52 dia
2.5
55
2,5
PK. 02. 06. 01. 01
PULLEY
Stage
Mass
Scale
T
Rev.
Sheet
Doc. No.
Stg.
Date
Done by
Names
Sheet No.
No. of sheets
Steel Grade 40
USSR Std.
KMT
2-118-FP
PK. 02. 06. 01. 02
SLEEVE
Bronze Grade ОЦС 5-5-5
USSR Std.

Fig. 555

PK. 02. 06. 01. 00



*Dimension for information only

Dwg. size	Zone	No.	Designation	Name	Qty	Notes
				Parts		
II		1	PK. 02. 06. 01. 01	Pulley	1	
II		2	PK. 02. 06. 01. 02	Sleeve	1	
				Standard items		
		3		Screw M8×16.58 USSR Std.	V	

					PK 02.06.01.00	
Rev.	Sheet	Doc. No.	Sig.	Date	PULLEY	Stage T / Mass / Scale 1:2
Done by / Names						Sheet No. / No. of sheets
						KMT 2-118-FP

Fig. 556

obtain a comprehensive idea of the shape and dimensions of the article.

In choosing a scale, full size (scale 1:1) is to be preferred. However, for articles of a very small or a very large size, the scale should be greater or smaller than the full size.

The size of the sheet should be selected so that the space is properly utilized.

In the assembly drawing (Fig. 557), the "Guide Pulley" is drawn in its working position. The drawing consists of the main view, top view, left-hand view, Sections *B-B* and *C-C*, and a view facing arrow *A*.

A broken-out section is given on the main view to show the bolts fastening together parts *2* and *3*.

A part of the section in the top view shows the joint between parts *1*, *2* and *5*.

The broken-out section on the left-hand view shows how part *2* is secured to part *4* by screws *7*.

The shape of the recess in part *2* is visible in the view facing arrow *A*.

Lubrication holes and channels are shown in Section *B-B*.

The scale and paper sheet size are chosen after measuring the overall dimensions of the assembly unit. Using thin continuous lines, rectangles with sides equal to the corresponding overall dimensions of the views are drawn on the sheet. Sufficient space is left between the rectangles to draw in the leaders for the component numbers and the necessary dimension lines. The title block and parts list are placed in the lower right-hand corner of the drawing (Fig. 557).

First the main views of brackets *3* and *2* are made, taking all the dimensions from the previously made sketches.

In most cases, the sequence followed in assembling the component parts governs the order to be followed in drawing the assembly unit.

In the present case, parts *2* and *3* are fastened together by bolts, then the sleeve is press-fitted into the pulley and is locked with the set screw. The hole for the screw is drilled and tapped in the two parts after their assembly.

Assembly unit *1* consisting of three component parts is inserted between the prongs of bracket *2*. Then axle *5* is inserted into the bores of bracket *2* and the sleeve in the pulley. Locking strip *4* is inserted into its slot in axle *5* and is then secured by screw *7* to bracket *2*. Grease fitting *9* is press-fitted into axle *5* beforehand.

After drawing all the views, overall and coupling dimensions are indicated, as are the symbols for fits and tolerances. Fits and tolerances are not shown in training drawings.

Shown on an assembly drawing are all the required installation and coupling dimensions, as well as those needed for information (see Fig. 557).

The elements of an article which are linked in some way to mating articles, for example, gears which mesh with the gears of another article, should have a note indicating the module, number of teeth and hand (for helical gears).

Dimensions given for the purpose of information, and indicated in the assembly drawing with an asterisk, are not required to assemble or inspect the article.

16. ASSEMBLY DRAWINGS OF PERMANENT JOINTS

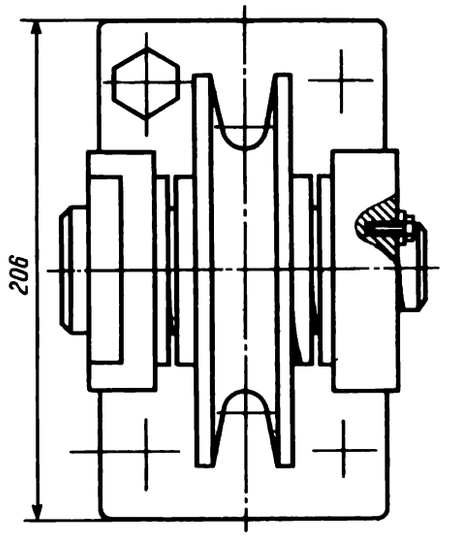
Assembly drawings of permanent joints include those of assembly units made up of components joined together by welding, brazing, soldering, adhesive bonding, riveting, and moulding, or obtained by moulding a plastic around a metallic insert, etc. The pertinent standards indicate how assembly drawings and parts lists are to be made for all cases of permanent joints, whether they are for job-lot or lot and mass production.

Instructions for making assembly drawings of certain permanent joints are given below.

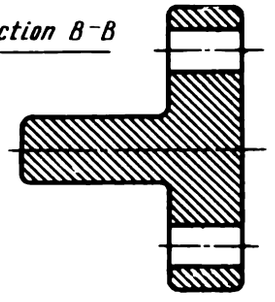
(a) *Assembly Drawing of a Weldment*

An example is given in Fig. 558 of an assembly drawing of a weldment consisting of component parts manufactured to their own part drawings. The assembly drawing (Fig. 558) has symbols showing the required types of welds in accordance with the rules given in Chap. 5. Eyepiece *3* is welded to plate *1* with a T joint (T10). To make such a weld, one edge of the eyepiece should be symmetrically bevelled on each side. The size of the bevels is specified by the standard for the T10 joint. To obtain the required accuracy in the relative positions of the holes in boss *2* and eyepiece *3*, these holes are made according to the assembly drawing after the welding operation (Fig. 558). Therefore, these holes are not to be shown on the part drawings of the boss and eyepieces. Since a working (detail) drawing with all the rquired dimensions is commonly made for each component of a weldment,

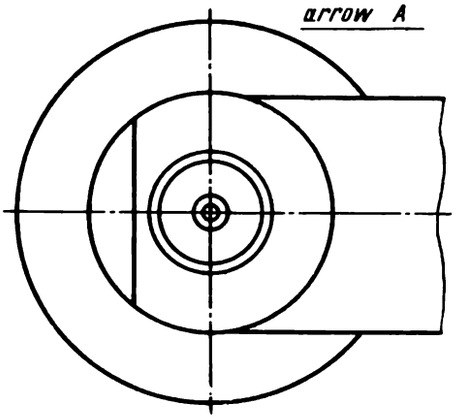
PK. 02. 06. 00. 00. AD



Section B-B



View facing arrow A



* Dimension for information only

Dwg. size	Zone	No.	Designation	Name	Qty	Notes
				Documentation		
22			PK. 02. 06. 00. 00	Assembly drawing	1	
				Assembly units		
11		1	PK. 02. 06. 01. 00	Pulley		
				Parts		
11		2	PK. 02. 06. 00. 01	Bracket	1	
11		3	PK. 02. 06. 00. 02	Bracket	1	
11		4	PK. 02. 06. 00. 03	Locking strip	1	
11		5	PK. 02. 06. 00. 04	Axle	1	
				Standard items		
				Bolt M16 × 80. 58		
		6		USSR Std.	4	
				Bolt M6 × 20. 58		
		7		USSR Std.	2	
		8		Nut M16.5 USSR Std.	4	
				Grease fitting V-2		
		9		USSR Std.	1	

Rev.	Sheet	Doc. No.	Sig.	Date
Done by		Names		

PK. 02. 06. 00. 00. AD

GUIDE PULLEY
ASSEMBLY DRAWING

Stage	Pages	Scale
T		1:2

Sheet No. No. of Sheets

KMT
2-118-FP

Fig. 557

the assembly drawing (Fig. 558) has only dimensions required for welding or for machining the weldment. If a weldment is made up of a small number of component elements of a very simple shape, all the dimensions can be put on the assembly drawing without making separate part drawings. In this case, the letters *ND* (no drawing) are to be written into the "Dwg. size" column of the parts list.

(b) *Assembly Drawing of a Hard-Faced Article or a Moulded Article with an Insert*

Items manufactured by hard-facing or by casting or moulding a metal or a plastic or rubber around some or all the surfaces of an inserted part can be called reinforced items.

The drawings of such items resemble assembly drawings.

No separate drawings are made of the metal applied in hard-facing, or of the alloy, plastic or rubber which covers or is joined to or moulded over the insert, or of a casting which joins (in the pouring process) several inserts. Neither do these items have designations. They are written into the parts list as materials, indicating their mass in the "Qty" column and the unit of measurement in the "Notes" column.

The part which is to be hard-faced, or the insert in the mould, is usually manufactured to a special drawing. It is permissible in simple cases to make this part from dimensions shown in the assembly drawing. Such an assembly drawing also specifies all the required dimensions of the finished (moulded or cast) assembly unit, data on the material and all the other information necessary to manufacture and inspect the item. For this purpose, the letters *ND* (no drawing) are put in the "Dwg. size" column of the parts list in place of the sheet size. In the "Name" column, under the name of the item, data is given on the required material.

The assembly drawing "Tip" (Fig. 559) is to be used to machine the steel stem, to mould capron *2* over the stem as an inserted component and to carry out all finish-machining operations.

17. READING TRAINING ASSEMBLY DRAWINGS

To read an assembly drawing means to:

(1) determine the shape, purpose and interaction of the component parts shown on the assembly drawing;

(2) find out the mutual position of the components and the methods whereby they are joined together;

(3) establish the purpose, design, and the principle of operation of the article shown.

To read an assembly drawing, it is necessary to start with carefully studying it. First the component parts are determined by reading over their names, number and other information about them in the parts list. From the component numbers in the parts list and on the drawing, it is necessary to identify all the components and get a general idea of their shapes and dimensions. This can be made easier by remembering that the views are projections of one another and that in different sectional views the same component is hatched in the same direction, while adjacent components are hatched in different directions.

The reading of an assembly drawing can be substantially facilitated if there is an opportunity to study the principle of operation of the item from some other document (for instance, an explanatory note, machine certificate and service manual, or a detailed description).

The component parts are not machined to the assembly drawing (except for cases of machining in assembly) and, consequently, the parts can be more simply depicted. For example, it is unnecessary to indicate chamfers, rounded corners, grooves, depressions, projections, knurling, etc. These simplifications are not applied when parts are to be made from the assembly drawing.

18. DETAILING AN ASSEMBLY DRAWING

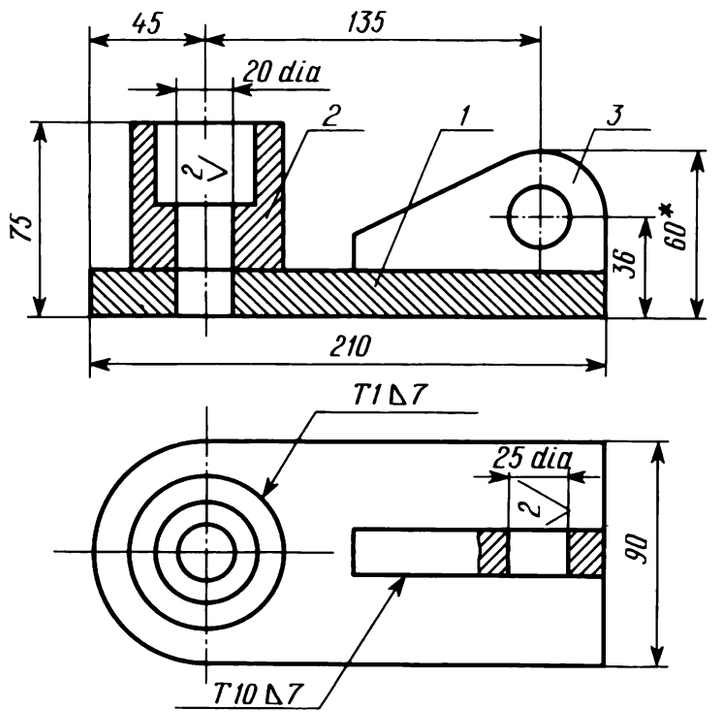
Under shop conditions, an assembly drawing is used to assemble and inspect the article being manufactured.

In the draughting office, an assembly drawing may be used to make the detail drawings of the components of the article.

Making detail drawings from an assembly drawing is called detailing.

The training assembly drawing in Fig. 560 is of a "Valve for Curing Shell Moulds". Its parts list is given in Fig. 561. Before making the detail drawings, it is necessary to read the description of the valve, read the parts list, and get an idea of its shape and the shapes of its component parts (Fig. 562). In our example, the "Body", Figs. 560 and 562, is connected by the right-hand

MD. 00. 03. 01. 00

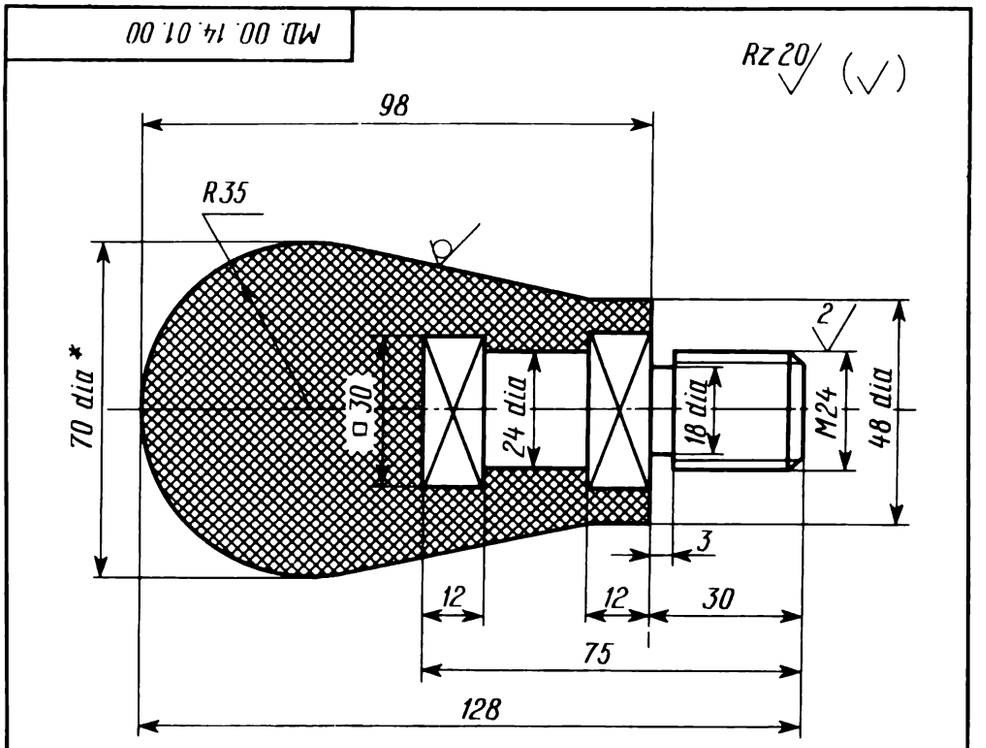


1. Electrodes Grade 342 USSR Std.
2.*Dimensions for information only

Dwg.size	Zone	No.	Designation	Name	Qty	Notes
				Parts		
II		1	MD. 00. 03. 01. 01	Plate	1	
II		2	MD. 00. 03. 01. 02	Boss	1	
II		3	MD. 00. 03. 01. 03	Eyepiece	1	

Rev.	Sheet	Doc. No.	Sig.	Date	MD. 00. 03. 01. 00			
					SUPPORT	Stage	Mass	Scale
Done by		Names				T		1:2
						Sheet No.	No. of sheets	
						KMT 2-118-FP		

Fig. 558



Dwg. size	Zone	No.	Designation	Name	Qty	Notes
				Parts		
		1	MD. 00. 14. 01. 00	Stem	1	
				Steel Grade 20 USSR Std.		
				Material		
		2		Capron		
				Grade BT	0.2	kg

Rev.	Sheet	Doc. No.	Sig.	Date	MD. 00. 04. 01. 00			
					TIP	Stage	Mass	Scale
						T		1:1
Done by		Names				Sheet No.	No. of sheets	
						KMT 2-118-FP		

Fig. 559

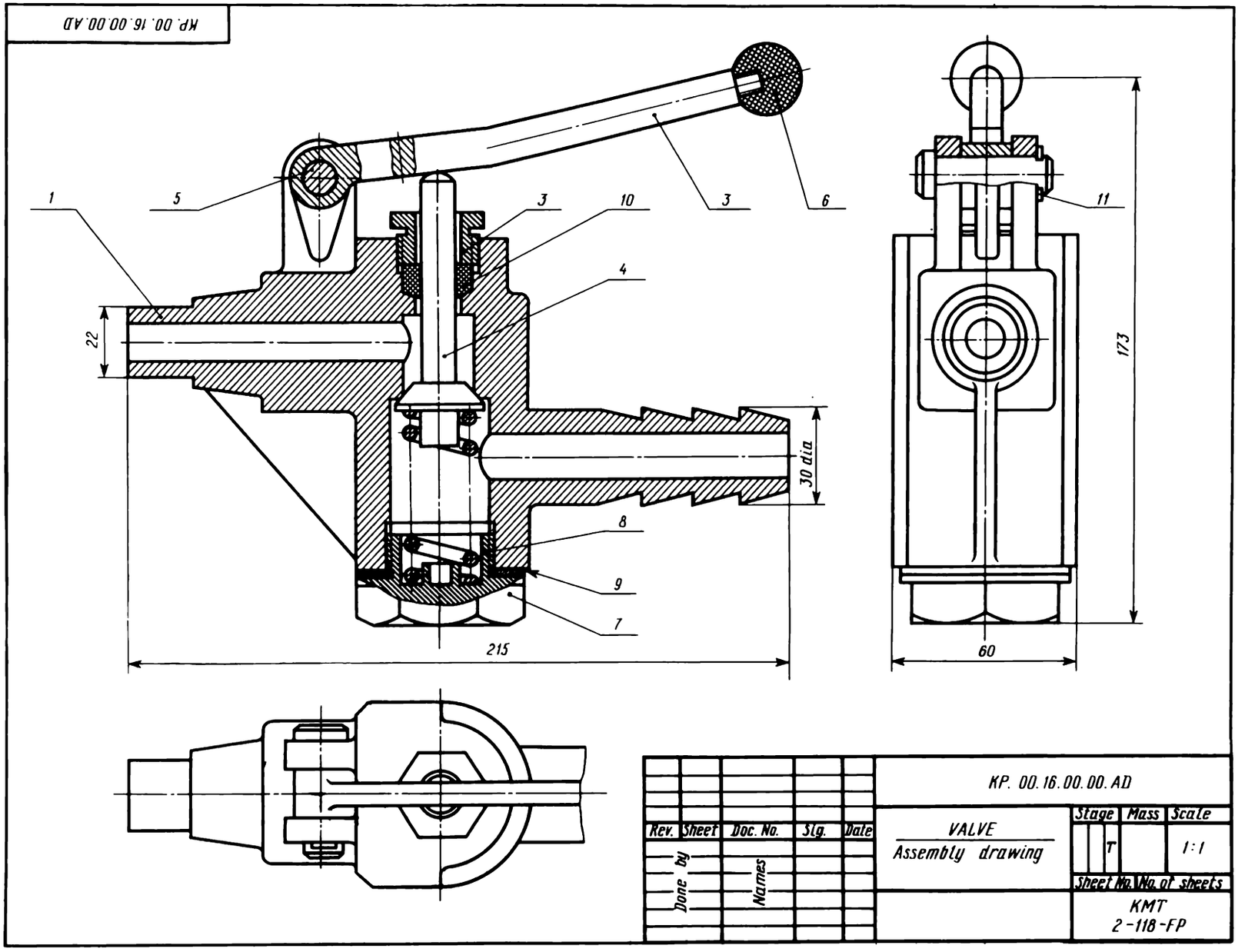

KP. 00. 16. 00. 00. AD
1
5
3
10
3
6
4
22
30 dia
8
9
7
215
11
173
60
KP. 00. 16. 00. 00. AD
VALVE
Assembly drawing
Rev.
Sheet
Doc. No.
Sig.
Date
Done by
Names
Stage
Mass
Scale
T
1:1
Sheet No.
No. of sheets
KMT
2-118-FP

Fig. 560

connection pipe through a rubber hose to a cylinder holding carbon dioxide. Through open valve member *4* and the right-hand nozzle, the carbon dioxide gas is blown onto the surface of the mould. In the closed position, valve member *4* is held against its conical seat in body *1* by spring *8*.

To open the valve, it is necessary to depress the right end of lever *2* with ball handle *6*, overcoming the resistance of spring *8*.

Lever *2* turns about pin *5* which is fitted into the holes in the lugs of body *1*. A lug on the lever bears against body *1* and thereby restricts the distance the lever can travel upward. Pin *5* is kept from coming out of the holes in the lugs by cotter pin *11*.

The force exerted by spring *8* on valve member *4* can be regulated by turning adjusting nut *7*.

Gasket *9* seals off the clearance between body *1* and nut *7*.

Leakage of carbon dioxide gas through the clearance between the stem of valve member *4* and the hole in body *1* is prevented by plastic packing rings *10*. Turning gland nut *3* compresses packing rings *10*, spreading them to seal the valve stem.

The slot under valve member *4* enables the member to be engaged by a tool in lapping-in the conical surfaces of the valve member and seat.

When the purpose and design of the assembly unit (Fig. 560) are clear, and the student can visualize the shape of each component part (Fig. 562), he can begin to make the *detail drawings*. First, the required (minimum) number of representations is assigned for each part. For instance, a single representation — the main view with a frontal section — is sufficient to manufacture the bushing (Fig. 563*a*). Two representations will be needed for the support (Fig. 563*b*), four representations for the bracket (Fig. 563*c*), etc.

The views of the parts on the working drawings do not necessarily have to be arranged in

Format	Zone	No.	Designation	Name	Qty	Notes
				Documentation		
A4			KP.00.16.00.00	Assembly drawing		
				Parts		
A2		1	KP.00.16.00.01	Body	1	
A1		2	KP.00.16.00.02	Lever	1	
A1		3	KP.00.16.00.03	Gland nut	1	
A1		4	KP.00.16.00.04	Valve member	1	
A1		5	KP.00.16.00.05	Pin	1	
A1		6	KP.00.16.00.06	Ball handle	1	
A1		7	KP.00.16.00.07	Cap nut	1	
A1		8	KP.00.16.00.08	Spring	1	
A1		9	KP.00.16.00.09	Gasket	1	
A1		10	KP.00.16.00.10	Packing ring	2	
				Standard items		
		11		Cotter pin 5×20 USSR Std.	1	
				KP.00.16.00.00		
Rev.	Sheet	Doc. No.	Sig.	Date		
Done by		Names			VALVE	Stage: — / Sheet: 1 / No. of sheets: 1
					KMT	

Fig. 561

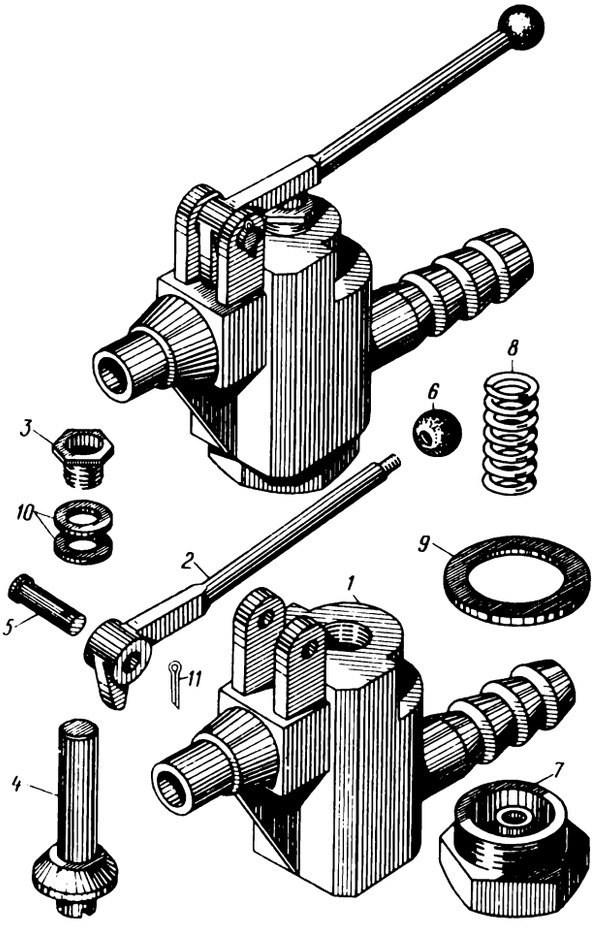


Fig. 562

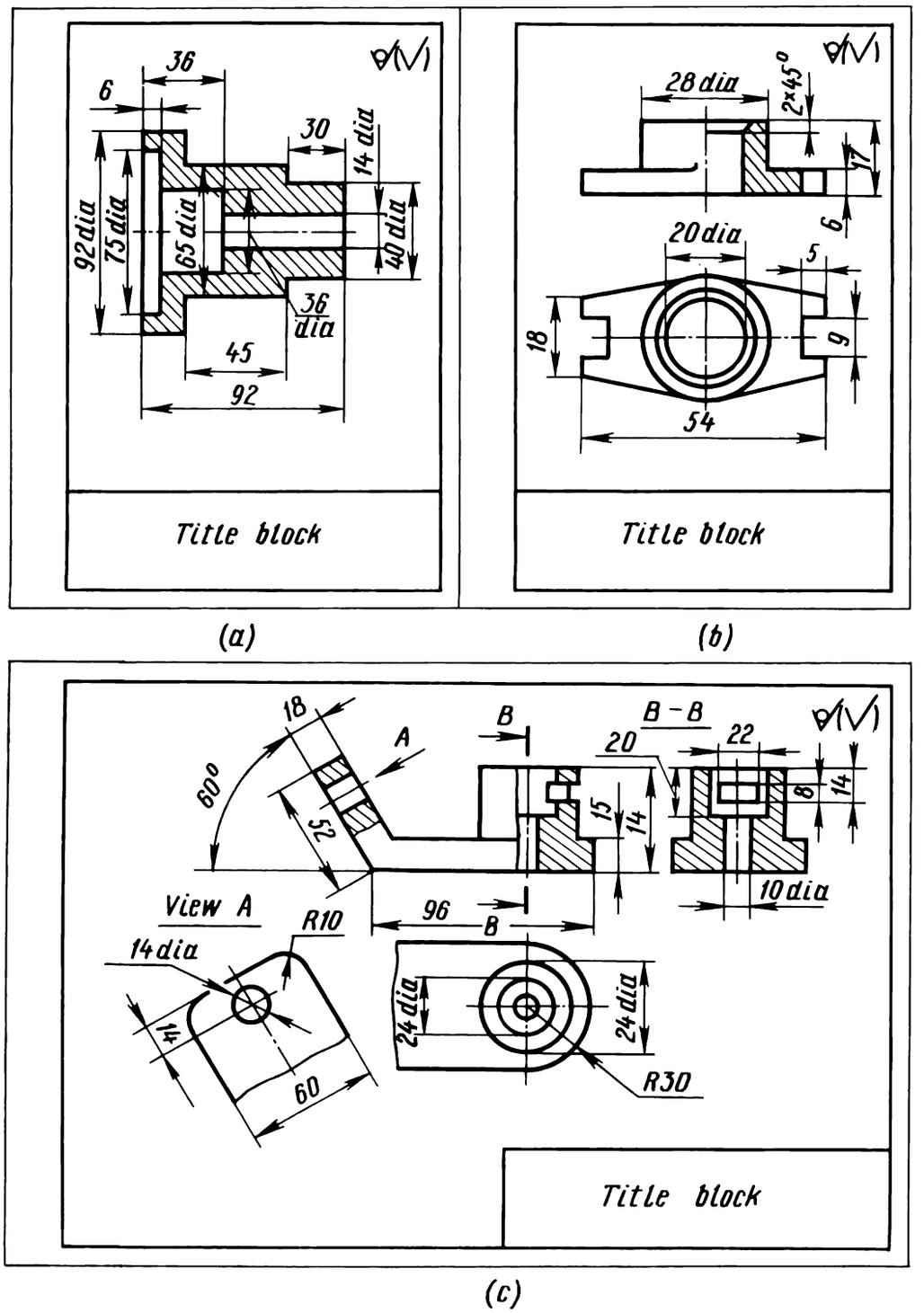

36
6
30
14 dia
92 dia
75 dia
65 dia
40 dia
36 dia
45
92
Title block
(a)
28 dia
2×45°
17
6
20 dia
5
18
9
54
Title block
(b)
18
A
B
B - B
22
20
60°
52
15
14
8
14
10 dia
View A
R10
96
B
14 dia
41
60
24 dia
24 dia
R30
Title block
(c)

Fig. 563

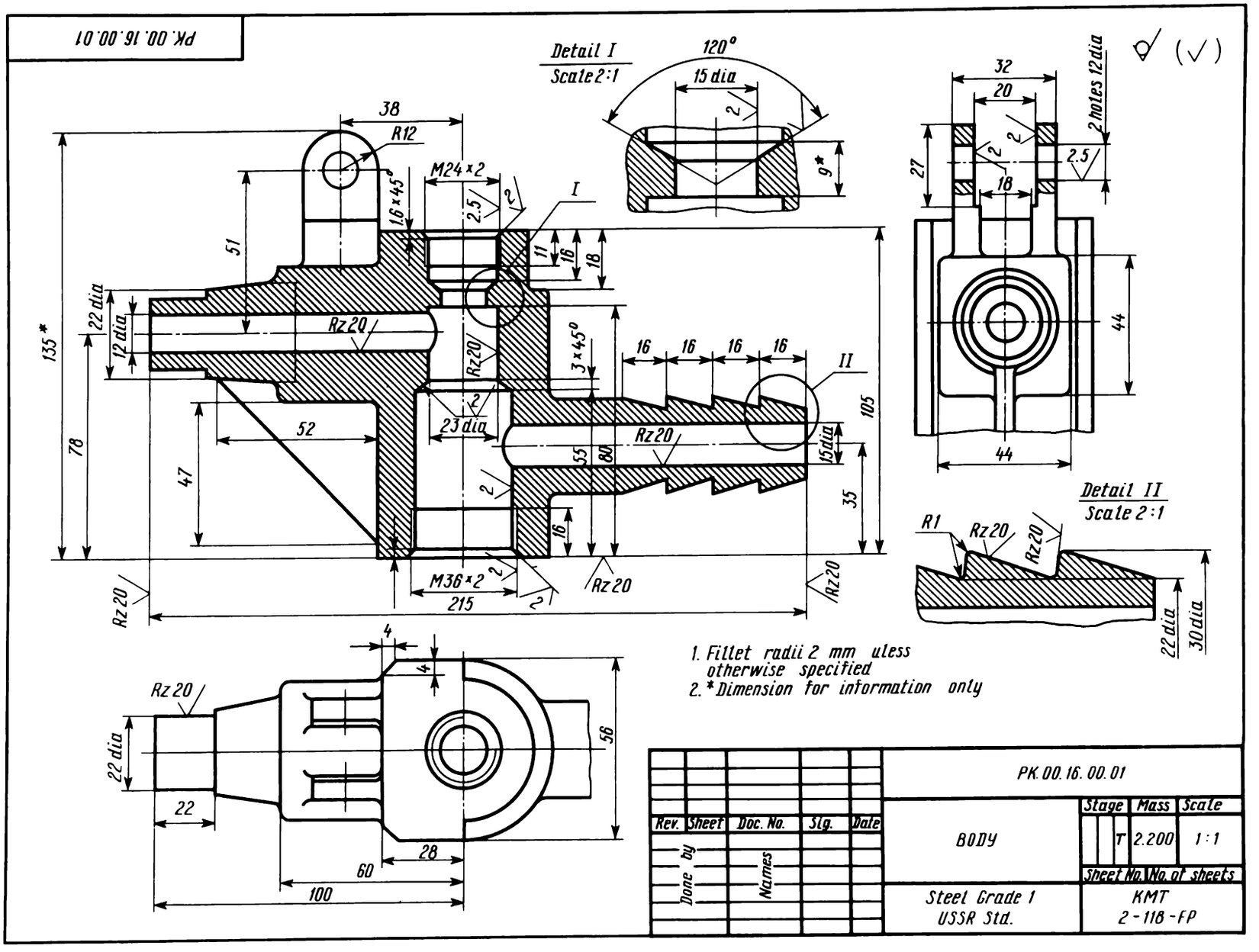

PK.00.16.00.01
Detail I
Scale 2:1
120°
15 dia
2
9*
38
R12
M24×2
1.6×45°
2.5
I
51
11
16
18
135*
22 dia
12 dia
Rz20
3×45°
16 16 16 16
II
105
52
23 dia
Rz20
55
80
15 dia
78
47
35
M36×2
215
Rz20
4
56
22 dia
22
28
60
100
32
20
2 holes 12 dia
27
2.5
18
44
Detail II
Scale 2:1
R1
Rz20
30 dia
1. Fillet radii 2 mm uless otherwise specified
2. * Dimension for information only
PK.00.16.00.01
BODY
Stage
Mass
Scale
T
2.200
1:1
Sheet No.
No. of sheets
Steel Grade 1
USSR Std.
KMT
2-118-FP
Rev.
Sheet
Doc. No.
Sig.
Date
Done by
Names

Fig. 564

the same way as in the assembly drawing. All views, sections and other representations should meet the requirements of the drawing standards. The scale is selected for each part to suit its size and shape. The more intricate the shape, the greater the number of contour and dimension lines there will be on the drawing. Consequently, such drawings should be drawn to a larger scale.

It is good practice to show small grooves, lugs and projections as removed elements drawn to a larger scale.

All detail drawings are to be made on paper sheets of standard sizes.

The detail drawing of the valve body is illustrated in Fig. 564. To fully reveal all the features and elements of this part, it is necessary to draw a frontal section, the left-hand view and the top view. The frontal section shows all the cavities and holes; the left-hand view with a broken-out section shows the holes in the lugs.

All of these views can be accommodated on a size *12* sheet if drawn to a scale of 1:2.

After drawing all the required views, the surface roughness symbols are indicated, dimension and extension lines are drawn and the figures are written for the dimensions. The grade of the material is written into the title block.

The drawings of all the other component parts of the assembly unit are made in a similar way.

Drawings of standard items are not usually made. If this is ever required, the dimensions are taken from the corresponding standards in accordance with the designations of the items as written in the parts list.

19. HANDLING OF INSTRUMENTS, STENCILS AND TEMPLETS IN MAKING DRAWINGS

Making drawings is a very laborious job. Various drawing instruments and devices have been developed by means of which the time required for making a drawing is reduced several-fold.

Thus, for instance, a cross-hatching instrument (Fig. 565) greatly increases the productivity of the draftsman, also ensuring a high quality of cross-hatching.

Pencil sharpeners and electric erasers are available.

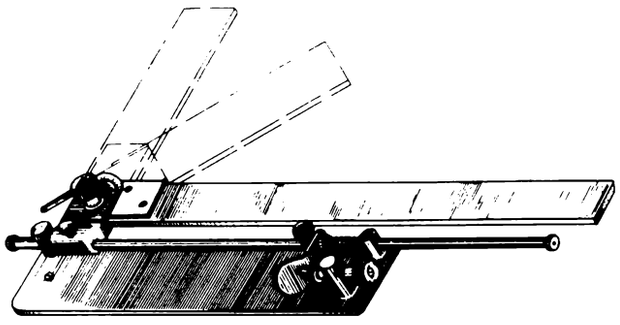


Fig. 565

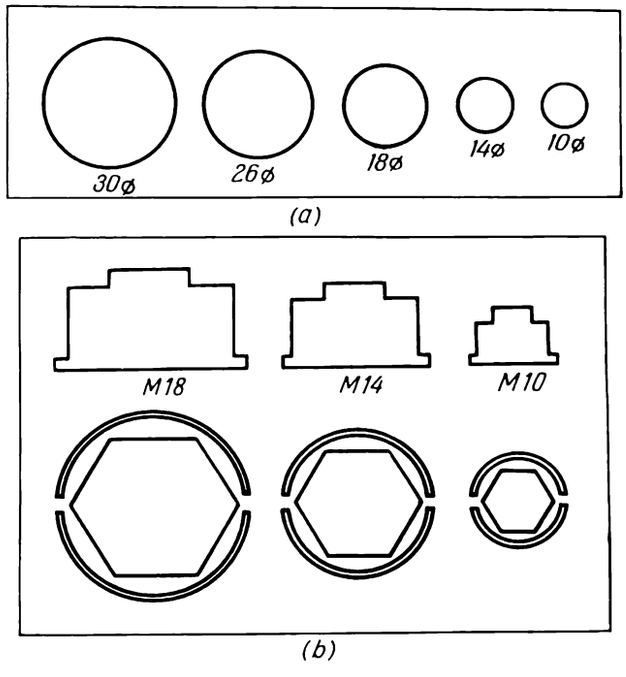


Fig. 566

Bolts, screws, nuts, rivets, various conventional symbols, circles, arcs are drawn with the aid of stencils made of transparent materials (celluloid, organic glass). Using the stencils shown in Fig. 566*b* the draftsman can draw nuts and washers of three different diameters, and the stencils illustrated in Fig. 566*a* make it possible to describe circles of five different diameters. Various line conjunctions are drawn by means of a radius templet shown in Fig. 567. Arcs of 15 different radii can be obtained by using this templet.

One time-saving procedure makes use of what may be called appliques as in dress-making. These are three-projection drawings of fre-

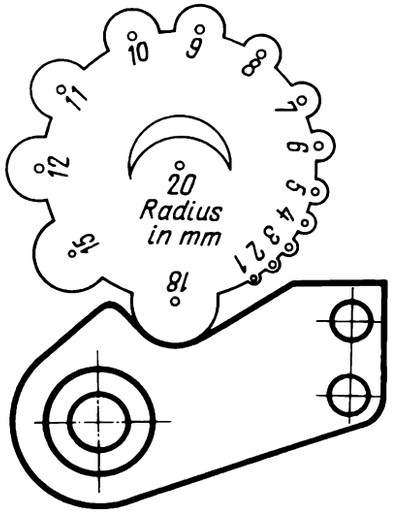


Fig. 567

quently used standard parts and units printed on paper or blue-printed. Instead of drawing the same part over and over again the draftsman merely cuts out the views and pastes them on his assembly drawing.

Questions

1. How are standard parts, for instance, a key, nut, ball bearing, dowel pin, etc., designated in the bill of material?
2. What packing devices do you know? Describe their fields of application.
3. How are part numbers arranged on an assembly drawing?
4. What are the definitions for interchangeability, tolerance, fit, deviation, clearance, and limit sizes?
5. What systems of fits and tolerances are used in mechanical engineering? How are these systems designated on assembly drawings?
6. How many grades of accuracy and what fits are encountered in machine units and how are they designated on assembly drawings?
7. When is the position of cutting planes not indicated, and the section obtained not accompanied by an inscription?
8. What are the steps in making an assembly drawing of an article from its model?
9. How are the boundaries of contacting parts and assembly units determined on assembly drawings? What lines are used?
10. What are the conventionalities for representing springs on assembly drawings?
11. How is an assembly drawing dimensioned?
12. What conventionalities are used in representing welded structures on assembly drawings?

Exercise 78

Make sketches, from models, of the parts of a simple unit (for instance, a bearing, valve, etc.) and make its assembly drawing from the sketches.

CHAPTER 8

READING AND DRAWING DIAGRAMS

Modern mechanical engineering is characterized by a high level of mechanization and automation which results in more complicated machines, machine tools, instruments, and apparatus and the use of mechanical, pneumatic, hydraulic, and electrical devices. Therefore, it is difficult to learn the operating principle of modern equipment using only general views and assembly drawings. That is why, in addition to general views, simplified or schematic representations are used which make it possible to grasp much more rapidly the methods of transmitting motion, as well as other functions of a mechanism.

Hence the necessity of studying, reading, and drawing gearing and other diagrams.

At first the student must learn the conventional symbols, i.e., simplified representations of various machine elements.

Special symbols for gearing diagrams are stipulated in the USSR Standard and Table 28 illustrates some of them. Conventional symbols for the main elements of hydraulic diagrams are given in Table 29, those for pneumatic diagrams

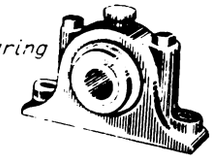
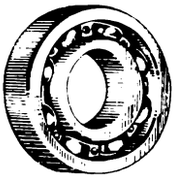
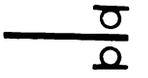
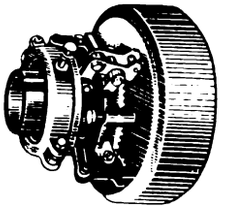
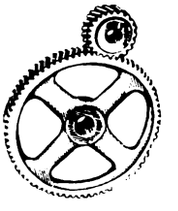
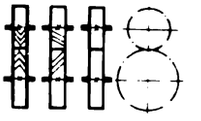
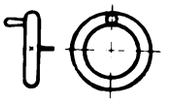
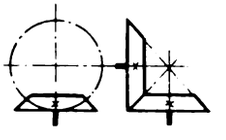
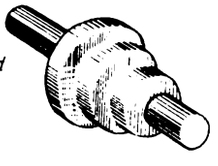
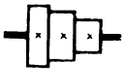
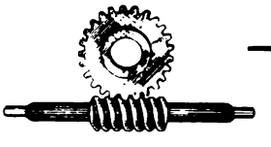
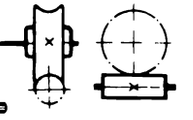
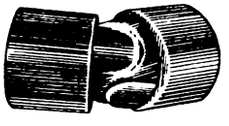
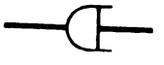
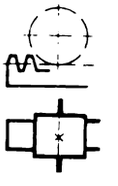
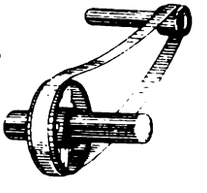
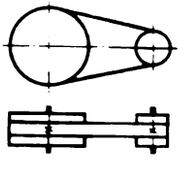
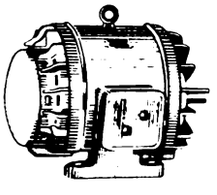
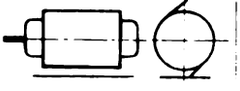
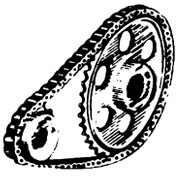
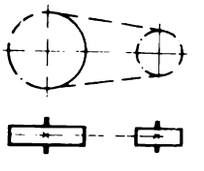
Name	Part	Symbol	Name	Part	Symbol
Axle, shaft, rod			*Motion screw*		
Radial slide bearing on a shaft			*Radial friction bearing on a shaft*		
Friction disk clutch			*Spur, helical and herring bone gearing*		
Handwheel			*Revel gearing*		
Step pulley fixed on a shaft			*Worm gearing*		
Universal coupling linking two shafts			*Rack-and pinion gearing*		
Compression spring					
Shift lever			*Flat belt drive*		
Electric motor on feet			*Chain drive*		

Table 29

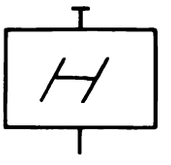
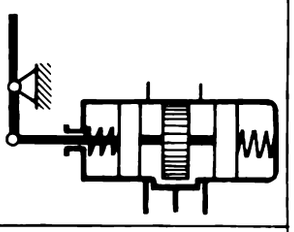
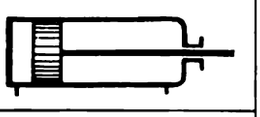
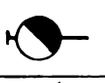
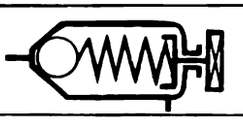
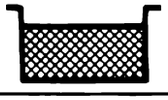
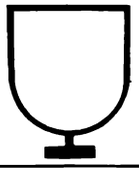
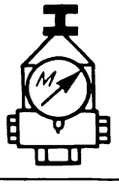
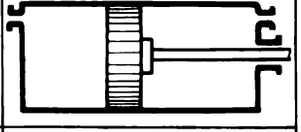
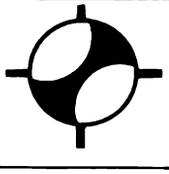
Name	Symbol
Liquid piping	
Flanged pipe	
Tank with liquid	
Pump	
Hand-controlled reverse valve	
Hydraulic (power) cylinder	
Straight tee-piece	
Throttle (controls liquid and gas flow)	
Return valve	
Safety valve	

Table 30

Name	Symbol
Air duct	
Straight tee-piece	
Pressure gauge	
Globe valve	
Plug valve	
Air filter, mesh type	
Water trap	
Reducing valve with a pressure gauge	
Pneumatic cylinder	
Rotary valve	

in Table 30. Some elements of electric diagrams are shown in Table 31 which is taken from the USSR Standard.

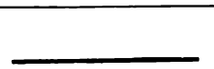
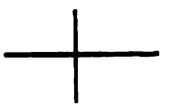
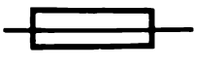
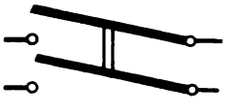
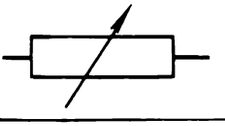
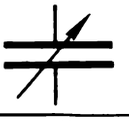
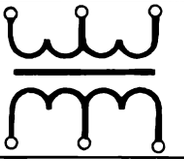
1. READING DIAGRAMS

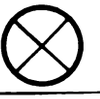
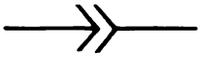
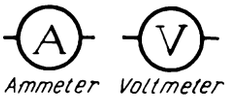
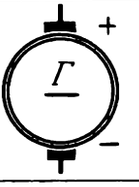
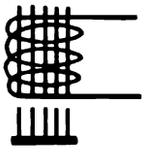
Prior to reading a diagram read the description of the design and principle of operation of the given mechanism. Then find the main units and parts of the mechanism represented on the accompanying diagram by conventional symbols.

The reading of gearing diagrams begins with the motor which usually transmits motion to all parts connected in a common kinematic chain. Then follow up this chain looking for conventional symbols in the USSR Standard.

Begin reading a pneumatic diagram with the air compression unit or air distribution network,

Table 31

Name	Symbol
Connecting wire	
Crossing-wire non-connected	
Tap	
Safety fuse	
Two-pole switch	
Adjustable resistor (rheostat)	
Adjustable capacitor	
Three-phase transformer	

Name	Symbol
Lighting lamp	
Pilot lamp	
Plug with receptacle	
Indicating instruments	 Ammeter Voltmeter
D. c. generator	
Three-phase electric motor	
Earthing	
Electromagnet	

a hydraulic one with the liquid feeding pump, and an electric one with the electric motor or current generator.

In making gearing diagrams of mechanisms incorporating gear drives attention should be given to some peculiarities of their representation. For instance, when drawn on a plane perpendicular to their axes, all spur gears are represented by dot-and-dash circles having the diameter of the pitch circle.

All gears are conventionally considered to be transparent and unobstructed by each other.

The axes of all gears are often conventionally brought to coincidence in one plane. Then the gears do not overlap, and such a diagram is easy to read.

Below we consider an example of a gearing diagram.

Assignment. Read and copy the gearing diagram of the drive for the housing screws of a 1000 mm blooming, fill in the list of parts (Fig. 568).

Description of the drive. The blooming is a large-size rolling mill employed for rolling heavy

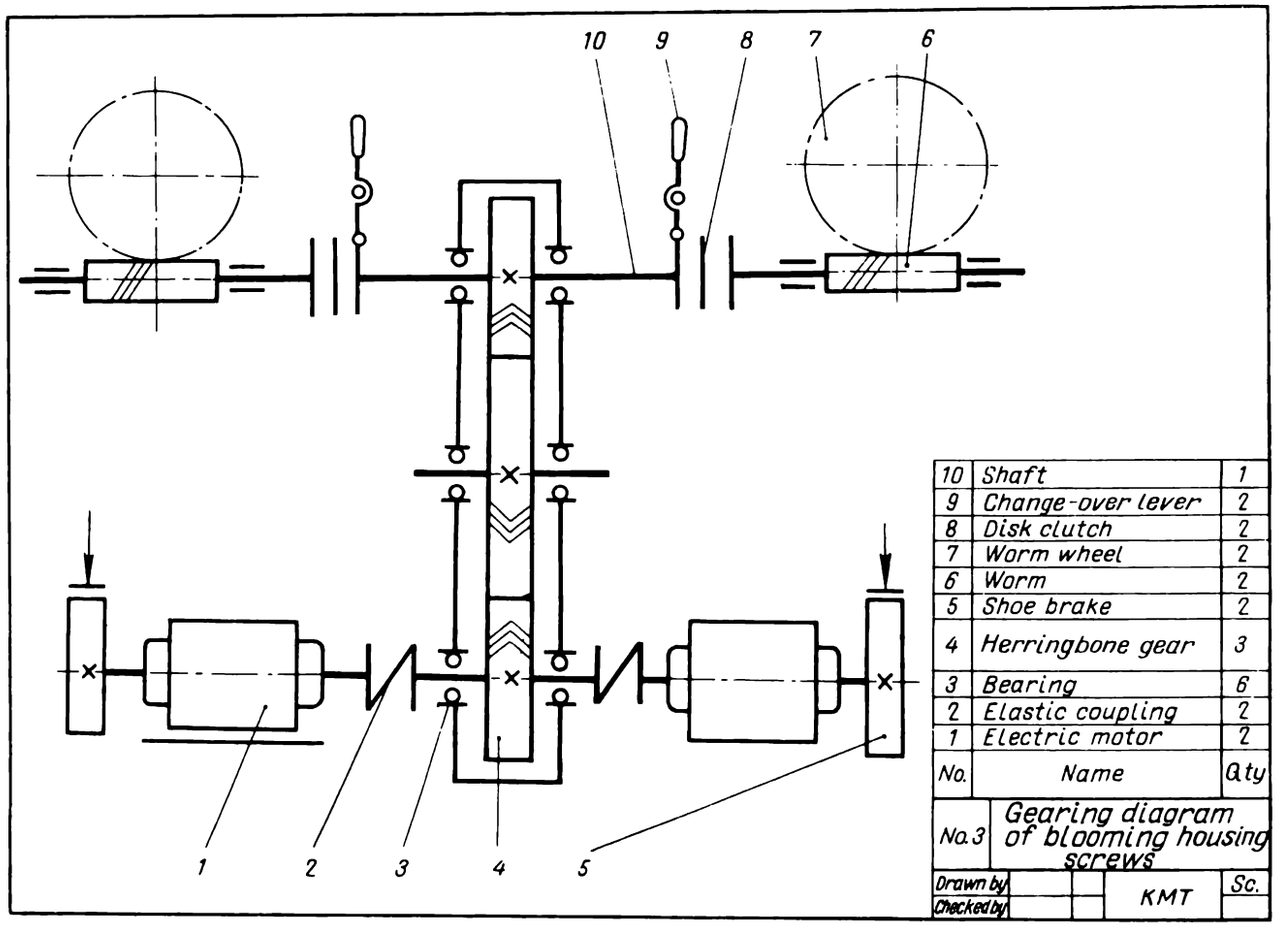


Fig. 568

steel ingots (weighing more than 1 ton) into blooms to obtain (by further rolling) beams, rails, strips, bars, sheets, etc.

The blooms are reduced in section by passing them repeatedly between two cylindrical rolls rotating in opposite directions. Each time a bloom is passed through the rolls the upper roll is moved downwards thus changing the distance between the working surfaces of the rolls. The upper roll journals are mounted in bearings which can be displaced vertically under the action of housing screws, the latter being set in rotary motion by a special drive comprising two electric motors. Rotation is transmitted from the motors to the two housing screws through a reducing gear which incorporates cylindrical herringbone gears and worm gearing. Between the reducing gear and each worm shaft there is a disk clutch coupled with a change-over lever. If the rollers are out of alignment, the worm gearing, and, consequently, the housing screw can be disconnected from the drive. Each electric motor is equipped with a shoe brake.

Reading the diagram. Following the above recommendations first find the electric motors *1* by comparing the diagram with Table 28, then the shoe brake *5* mounted on the shaft ends, and the elastic coupling *2* which connects the end of the motor shaft with the drive shaft of the reducing gear. Now identify the bearing *3*, herringbone gear *4*, disk clutch *8* equipped with change-over lever *9* and connected with shaft *10* of the reducing gear.

The worm gearing of the housing screw consists of worm *6* and worm wheel *7*. All the names of the units and parts should be entered into the list of parts under numbers corresponding to those on the drawing.

Consider an example of reading a combined (gearing and hydraulic) diagram of a hydro-

mechanical head for press-fitting machine parts (see Fig. 569). The head has a flange-type electric motor which actuates a motion screw through a V-belt and a worm drive. The screw displaces the nut connected with a hydraulic buffer comprising a hydraulic cylinder with a piston. The hydraulic buffer moves from left to right performing the working stroke of press-fitting a part. The chambers *A* and *B* of the cylinder are filled with oil. The oil in the chamber *A* is compressed during the working stroke thus pushing the piston and connecting rod which will press-fit the part. The pressing effort can be adjusted by changing the oil pressure in the chamber *A* which is accomplished by a safety valve.

On completion of the press-fitting operation the pressure acting on the connecting rod increases sharply, thus causing an increase in the oil pressure in the chamber *A*. The safety valve opens, letting the oil into the chamber *B*. As a result the connecting rod ceases to move, though the piston of the hydraulic buffer continues its motion. The latter is automatically stopped when the button of the reverse switch *K* of the electric motor touches the stop *S*.

At this moment the electric motor is reversed and the whole mechanism returns to the initial position. Under the action of the spring the piston moves to the extreme right position displacing the oil from chamber *B* to chamber *A* via the non-return valve. When the back of the hydraulic buffer touches the button K_1 of the limit switch, the electric motor is switched off and the hydromechanical head stops. The effort required for press-fitting is controlled by turning the screw which acts on the spring of the safety valve.

Reading the diagram. Begin by locating the electric motor (see Fig. 569), then find the symbol for the V-belt drive whose pulleys are mounted on the shafts with the aid of keys represented as *X* on the diagram. The driven shaft of the V-belt transmission with the larger pulley is mounted on two tapered roller bearings. The worm wheel is mounted below the worm on an intermediate horizontal shaft which also rotates in two tapered roller bearings. The intermediate shaft is joined with the screw of the hydraulic buffer by means of a safety clutch. The screw rotates in two similar bearings. Using Table 29 you can find the elements of the hydraulic equipment: the hydraulic cylinder (with a rod), whose left-hand chamber is connected with the safety valve and the non-return valve through a tee-piece.

Now let us read a pneumatic diagram. Fig. 570*b* shows the diagram of a pneumatic device designed for tightening large-size bolts. The device has a double-acting pneumatic cylinder, its piston reciprocating horizontally under the action of compressed air. Connected to the piston is a rod with rack teeth on the end, thus representing a rack which is in mesh with a pinion. Secured to the latter is a pawl engaged with a ratchet which is mounted on a spindle by means of a key and rotates it clockwise. When the pinion is reversed, the pawl slides along the teeth of the ratchet, and the spindle does not rotate. Hence, the piston, moving to the right, performs its working stroke during which the head spindle, fitted at the end with a socket wrench, will turn a bolt or a nut.

The piston is controlled by a hand-operated air distributing cock through which compressed air is fed from the mains to the right- or left-hand chamber of the cylinder. When the compressed air is fed to the left-hand chamber of the cylinder the air contained in the right-hand chamber flows out through the air distributing cock. Before entering the cylinder the compressed air is cleaned in the filter and water trap where the suspended particles and moisture are caught. On leaving the water trap the compressed air passes through a reducing valve fitted with a pressure gauge.

The reducing valve is intended to set up a definite effort on the piston rod and to maintain it during the whole operating time. A section of air mains with the water trap and filter

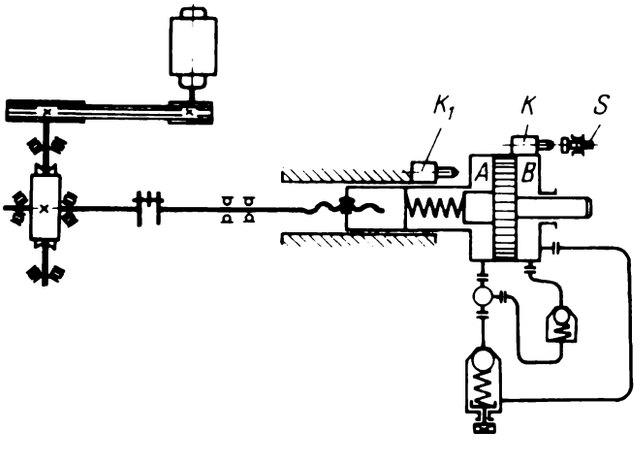


Fig. 569

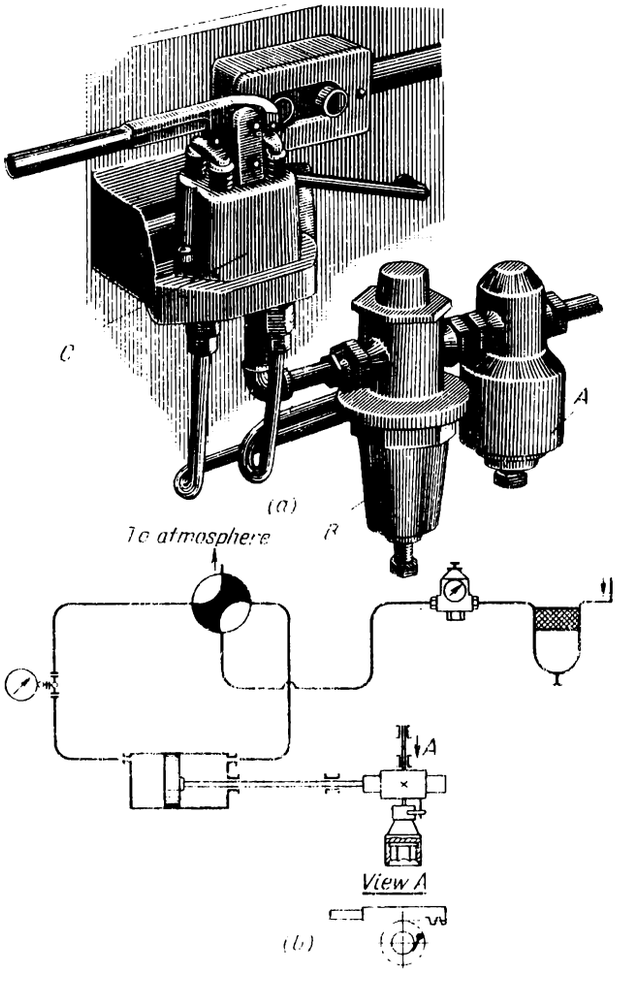


Fig. 570

(A), reducing valve *(B)* and air distributing cock *(C)* is shown in Fig. 570*a*.

The pneumatic diagram is read by using the conventional symbols contained in Table 30. Begin with the air mains shown in the right-hand top corner of the diagram (Fig. 570*b*) wherefrom the compressed air enters the filter and water trap. The diagram further shows the reducing valve with a pressure gauge. The air then flows to the distributing cock through which it enters both chambers of the cylinder. Mounted at the left is a pressure gauge connected to the pipeline by a tee-piece.

At the right-hand end of the piston rod are conventional symbols for the rack and pinion. Since a portion of the rack is obstructed by the pinion, an additional top view (View *A*) is given to show the rack and the ratchet mechanisms.

Finally, we shall consider an example of reading an electric circuit diagram.

To restore worn machine parts a newly developed electrovibration method of metal facing is used. A vibrating wire of the required [illegible] is continuously fed from a reel to the rotating part (see Fig. 571). The wire is [illegible] by two rollers of the feeding mechanism approaches the part end-wise through a tube which is vibrated by a three-phase electromagnet. The device is mounted on a welding generator. To ensure rotation the electric motor of the feeding mechanism, as well as the electromagnet of the vibrator, is fed with low-voltage [illegible] from a three-phase transformer.

The whole device, called [illegible] is mounted on a lathe carriage which moves slowly along the part. The electrical diagram of the device is shown in Fig. 571.

Begin reading the diagram with the generator designated by the letter *I* (see also Table 31). The wire from the [illegible] terminal of the generator is connected to the [illegible] through which the welding wire passes, the latter maintaining contact with the holder. The second wire from the negative terminal of the generator (designated as $-$) is connected to the work lead which is in contact with the part. The generator voltage is controlled by the [illegible] connected in parallel. The current before the wire is measured by a [illegible] connected ammeter. A variable load resistance is connected across the leads. At the bottom of the diagram is a three-phase mains (with a three-pole switch and fuses), from which current is fed to the

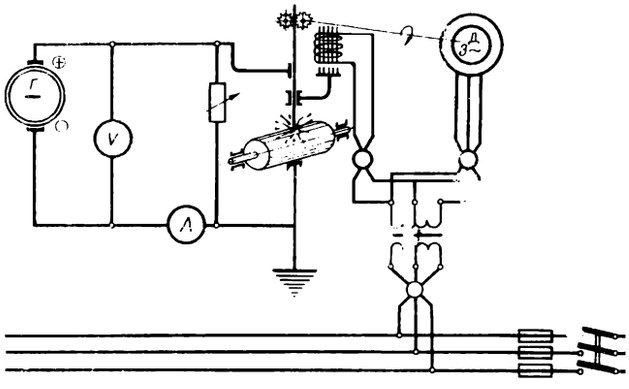


Fig. 571

transformer and then to the electric motor of the feeding mechanism designated as M3 a.c.

...he connection of the rotor of the electric ...tor to the axle of the wire feeding roller is ... by an inclined thin line.

... phases from the transformer are connect- ... e electromagnet of the tube vibrator.

MAKING GEARING DIAGRAMS

... a gearing diagram of the electricl ... studs portrayed in Fig. 572*a*. ...wing (a sectional view) is repre- ...2*b*. As can be seen from the ... has an electric motor *1* ...pur gear *2*, mounted on the ...o gears *3* and *4* mounted ... shaft. Gear *4* engages two ... The latter is freely fitted on spindle *9* which has a chuck *8* for grasping the stud. Internal gear *5* is mounted on ball bearings. Gears *5* and *10* are equipped with jaw-type half-couplings which can, during axial displacement of spindle *9*, engage its respective pins *6* and *11* rigidly mounted in the spindle. Under the action of spring *7* pin *6* is kept engaged with the half-coupling of gear *5*. This position corresponds to the working stroke of the device, during which rotary motion is transmitted from the electric motor to spindle *9* through gears *2*, *3*, *4*, and *5*.

When a stud is driven into a part to the end of the thread, the bevels on the jaws of the half-coupling of gear *5* begin sliding along pin *6* thus compressing spring *7*. This prevents the breaking of the stud. When the device moves upwards, the half-coupling of gear *5* and pin *6* are disconnected thus bringing gear *5* out of

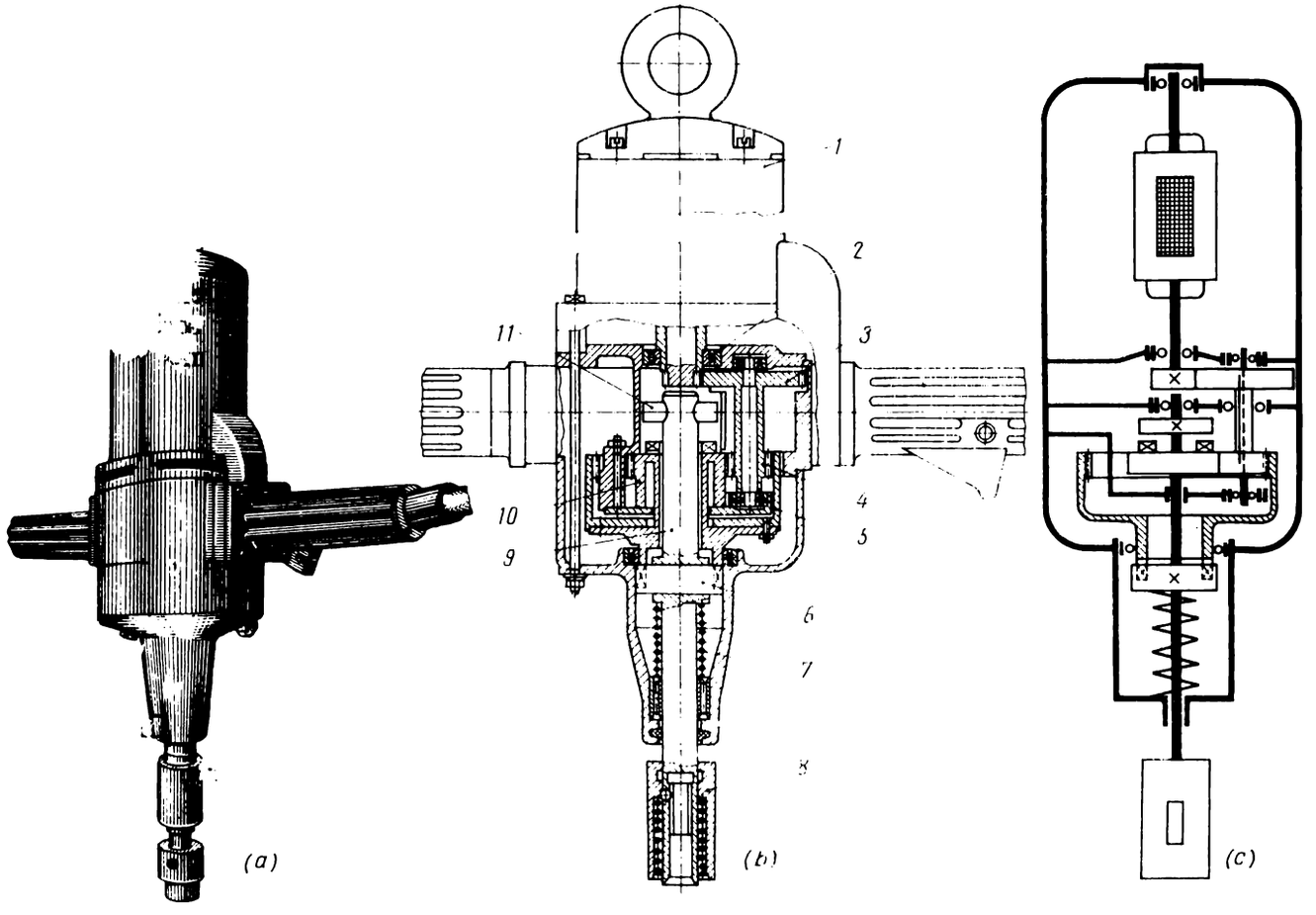


Fig. 572

engagement with spindle *9*. As a result, the half-coupling of gear *10* will engage pin *11*. Gear *10* becomes connected with spindle *9* setting it in motion in the reverse direction at double speed, since its diameter is half the diameter of gear *5*. Thus, the head fixed in the spindle of the device will be rapidly unscrewed from the threaded end of the stud.

It is rather difficult to understand the design and operating principle of the device by using its drawing shown in Fig. 572*b*, even if the description is available. Therefore, drawing a gearing diagram is of great help.

Here are the steps in making the diagram: draw the vertical axis of symmetry (see Fig. 572*c*); find the conventional symbol of a built-in electric motor in the USSR Standard and draw it on the diagram; then add the conventional symbols of the ball bearings for the shaft of the electric motor. At the lower end of this shaft draw a spur gear fastened with the aid of a key. Then show the two gears mounted on the intermediate shaft meshing with this gear (according to the above standard, all shafts and the spindle are drawn in heavy lines). The parts are drawn step by step from the electric motor to the spindle. The internal gear is given in a sectional view and its symbol slightly differs from the standard. The contour of the housing is represented arbitrarily.

Questions

1. What is the difference between the drawing of a machine or an assembly unit and its diagrammatic representation?
2. How are diagrams read?
3. What is the sequence of making a gearing, pneumatic, hydraulic or electric diagram?

Exercise 79

Read the hydraulic diagram of the circuit between a power hydraulic cylinder and a pump shown in Fig. 550 using the description below. Copy this diagram and fill in the list of parts using the conventional symbols of Table 29.

TO THE READER

Mir Publishers would be grateful for your comments on the content, translation, and design of this book. We would also be pleased to receive any other suggestions you may wish to make.

Our address is:
MIR PUBLISHERS,
2, Pervy Rizhsky Pereulok, 129820, Moscow I-110, GSP, USSR.

PRACTICAL BENCH WORK

N. MAKIENKO

The material is presented in the form of instruction sheets covering all the subjects of the syllabus. They are well illustrated. Exercises are given to be performed on trainers which simulate the typical working processes to acquire habits in carrying out the bench-work operations. Techniques are described for operating machine tools and handheld power tools; production tasks are illustrated with examples, solutions, and answers. Safety rules are given in each instruction sheet.

Intended for students and instructors at secondary vocational technical schools. Can be helpful in training fitters on the job apprenticeship basis in industry.

Contents. Recommendations and Advices. Training and Production Process Sheets: Flat Laying-Out; Metal Straightening, Bending, Chipping, Cutting, and Filing; Drilling Countersinking, Core-Drilling and Reaming of Holes; Thread Cutting; Riveting; Three-Dimensional Laying-Out; Hole-Filling and Fitting; Scraping; Lapping, Soldering, Brazing, Tinning, and Bonding; Production Tasks and Exercises; Basic Concepts of Industrial Engineering; Fundamentals of Measurement; Appendices.

THREAD-MILLING PRACTICE

F. BARBASHOV, Cand. Sc. (Eng.)

A textbook for training thread-milling operators. Outlines fundamentals and techniques of thread-milling operations. Describes new models of thread-milling machines, and electrical equipment, gives a short survey of numerically controlled machine tools.

Contents. General Outline of Manufacturing Enterprise and Workplace Arrangement. Accident Prevention, Industrial Hygiene, and Fire Protection. Operations Performed on Thread-Milling Machines. Tolerances and Fits. Measuring and Gauging Equipment. Methods of Measurements. Fundamentals of Thread Milling. Thread-Milling Cutters. Thread-Milling Machine. Electrical Equipment of Thread-Milling Machines. Scope of the Manufacturing Process. Mechanization and Automation of Production. Quality of Production. Reference. Index.